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Dosimetry in Diagnostic Radiology; A Guide for Meeting JCAHO and ACR Requirements and ICRP Recommendations

Mark C. Wrobel, Major, USAF

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Occupational and Environmental Health Directorate
Bioenvironmental Engineering Division
2402 E Drive
Brooks AFB, TX 78235-51144

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MARK C. WROBEL, Major, USAF, BSC
Chief, Radioanalytical Branch

LARRY T. KIMM, Major, USAF, BSC
Chief, Bioenvironmental Engineering Division

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Armstrong Laboratory (AFMC)
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13. ABSTRACT *(Maximum 200 words)*

Accreditation by the Joint Commission on Accreditation of Health Care Organizations (JCAHO) and the American College of Radiology (ACR) requires the monitoring of patient doses resulting from diagnostic x-ray procedures. The intent of these standards is to ensure that the risk or detriment posed by the radiation dose received by the patient is well below the benefit the patient receives from the diagnostic information provided by the examination. In addition, the International commission on Radiological Protection (ICRP) basic tenants concerning radiation protection in diagnostic radiology recommend that unnecessary exposures should be avoided, necessary exposures should be justifiable in terms of benefits what would not have otherwise been received, and that doses actually administered should be limited to the minimum amount consistent with the medical benefit to the individual patient. This report is intended to provide instruction and guidance for radiology sections of a clinic, hospital or medical center to determine patient dose resulting from conventional radiographic examinations. The report provides published dosimetric results from various studies to allow comparison with measured doses. Recommended action levels are presented to for identification and correction of abnormally high dose procedures. by integrating dose assessment into a departments regular quality control program, patient and staff exposures will be minimized while ensuring optimal image quality and compliance with accreditation standards.

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This report is strongly based on the recommendations found in AAPM Monograph 20, Specification, Acceptance Testing and Quality Control of Diagnostic X-Ray Imaging Equipment and the Radiological Society of North America 1996 Syllabus on Quality Improvement of Diagnostic X-Ray Imaging Equipment. Specifically, the chapters by Robert Dixon on patient dose determination in radiology, Dev Chakraborty on routine fluoroscopic quality control and Lawrence Rothenburg and Keith Pentlow on CT dose assessment were instrumental in creating this report.

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DOSIMETRY IN DIAGNOSTIC RADIOLOGY

INTRODUCTION

The requirement to estimate patient entrance-skin-exposure (ESE) in diagnostic imaging applications is found in the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) Standard for 1992 as DR 2.2.4.2 and is reflected in the 1996 standards in PI.3.3.1, PL.3.3.2, and PI.3.3.3. This requirement first appeared in the 1987 standards and stated that a qualified individual must "monitor doses from diagnostic radiology procedures." Following release of this standard, the American Association of Physicists in Medicine (AAPM), together with the American College of Radiology (ACR), attempted to provide guidance on interpretation and compliance with this standard(1,2). This JCAHO standard is no longer explicitly stated, but evaluation and determination of patient dose can be used effectively as a quality indicator for the diagnostic radiology department. Further, some clinics or medical centers may be required to assess patient dose based on state requirements. Observation of skin injury for certain fluoroscopy guided procedures has also provided increased impetus on assessing and tracking patient dose(3,4).

This report is intended to provide the clinic or medical facility the guidance necessary to measure patient dose to meet JCAHO requirements for a variety of imaging modalities. Measured doses (or exposures) can then be compared to either published national averages or the recommended limits from AAPM, ACR or the National Council on Radiation Protection and Measurements (NCRP) to help ensure patient dose is minimal while still maintaining acceptable diagnostic image quality.

CONVENTIONAL X-RAY SYSTEMS AND PORTABLE X-RAY

The intent of the JCAHO standard is to allow a comparison between the exposures resulting in a given facility with those assessed from national averages and standards of good practice(2).

The value to the Air Force in tracking patient dose includes this comparison, but also affords the department important information for quality control purposes, room by room comparisons, and occasionally medico-legal requirements, as in the case of fetal dose assessments. Assessing patient dose, and correcting abnormally high exposures assists in assuring that occupational and patient doses are as low possible and provides valuable information for patient counseling on radiation risk.

Dosimetry in Diagnostic Radiology

Patient organ doses cannot be measured directly without using relatively complex and/or invasive procedures. Instead, ESEs are recorded which can be measured simply and directly using any of a number of commercially available dosimeters. ESE measurements can then be extrapolated to provide organ doses for certain reference human geometries(5), from which an effective dose equivalent and estimate of risk for the procedure can be obtained.

National survey data on ESEs are available for a limited number of projections. The Nationwide Evaluation of X-Ray Trends (NEXT) study from 1984 through 1987 provided ESE data for posterior-anterior chest, anteroposterior abdomen, and anteroposterior lumbosacral spine according to screen-film speed(6). Kerlakes and Rosenstein also reported ESE data for a broad number of projections, for a reference adult patient, but these results are typically much higher then the NEXT data tables(7). Finally, federal radiation protection guidance was provided in 1978 which states that exposures to patients should be as low as reasonably

achievable without sacrificing diagnostic information. Further, measures should be taken to evaluate and reduce, where practical, exposures for routine nonspecialty examinations which exceed a list of specified Entrance-Skin-Exposure Guides (ESEGs)(8). Although somewhat dated, this latter data set provides a bottom line for determining if corrective actions are required. A comparison of these different data sets is provided in Table 1.

It is recommended that any exposures which are double the NEXT value for the appropriate speed system used, or an exposure that exceeds the Keriakes and Rosenstein data by more than 50% should be evaluated. ESEs should be assessed at least on an annual basis, and preferably on a semi-annual basis.

TABLE 1. Selected Guidance for Entrance-Skin-Exposure for Common Diagnostic Procedures

Projection	Handbook of Radiation Doses (mR)	NEXT (200 speed) (mR)(9)	NEXT (400 speed) (mR)	FRPG ESEG (mR)
Chest (PA)	25	25	15	30
Skull (Lat)	280	145	70	300
Abdomen (AP)		490	300	750
Cervical Spine (AP)	260	135	95	250
Thoracic Spine (AP)	665	260	145	900
Full Spine (AP)	280			300
Lumbar Spine (AP)	885	570	330	
Lumbo-Sacral Spine (AP)	910			1000
KUP (AP)	665			
IVP (AP)	559			
Retrograde Pyelogram (AP)				900
Hip (AP)	450			
Pelvis (AP)	545			
Dental/Bitewing			700 (1973 data) 334 (1981 data)	700

Measurement Methods

The entrance skin exposure, free-in-air, can be simply determined from the kVp, mAs, and source to patient distance for a given technique, if a series of radiation output measurements (exposure versus kVp) are available for a given x-ray tube at a known distance. By using this data, ESEs can be easily generated for all standard procedures using a simple spreadsheet.

Equipment

Critical to accurate exposure measurements is the use of an electronic dosimeter capable of measuring direct beam exposures at conventional diagnostic energies. Typical systems include:

a. Keithley 1(800)552-1115, Model 3505A Dosimeter with Model 96035 15cc Ion Chamber and Model 96020B 150 cc Ion Chamber (~$5600)

b. Nuclear Associates, Victoreen 1(516)741-3630, RadCheck+ with Fluoroscopic Exit Dose Ionization Chamber Model 06-524-1000 (~$2300).

c. Nuclear Associates, Victoreen 1(516)741-3630, Model 4000+ ($4605) and Model 4000M+ ($6658) with Fluoroscopic Exit Dose Ionization Chamber Model 6000-530B (~$1000)

d. Radcal MDH 1(818-357-7921), Model 1015 ($4160), Model 1515 ($5070), 2026MS ($3130) and 9015MS ($4985)

e. Gammex RMI 1(800)426-6391, Model 242 ($6000), Model 240A or Model DDS-1

Note that most AF medical equipment repair centers (MERCs) use the MDH 2025 or 2026 for their measurements. If a facility wishes to avoid the expense of acquiring there own dosimeter systems, they can most likely borrow, or share the use of these systems with a regional MERC. Similarly, a limited number of these systems is available for loan from this organization.

Procedures

Exposure data (radiation output) can be obtained directly from the annual calibration of an x-ray system (PCRI) performed by biomedical equipment repair technicians. The data is measured using a direct readout digital ion chamber, such as the MDH 2025. Similarly, this data can be measured in-house using any of the dosimeters listed above, and the following procedure:

1. Follow the manufacturers instructions to set-up and operate the specific dosimeter used. Note that electronic dosimeters normally require several minutes to "warm-up" before accurate measurements can be made.

2. Place the dosimeter on the exposure table, and center the x-ray tube over it at a distance of 20" to 40". Record this distance. Collimate the beam to at least several inches beyond the dimensions of the dosimeter. A conventional set-up for the measurements is shown in figure 1.

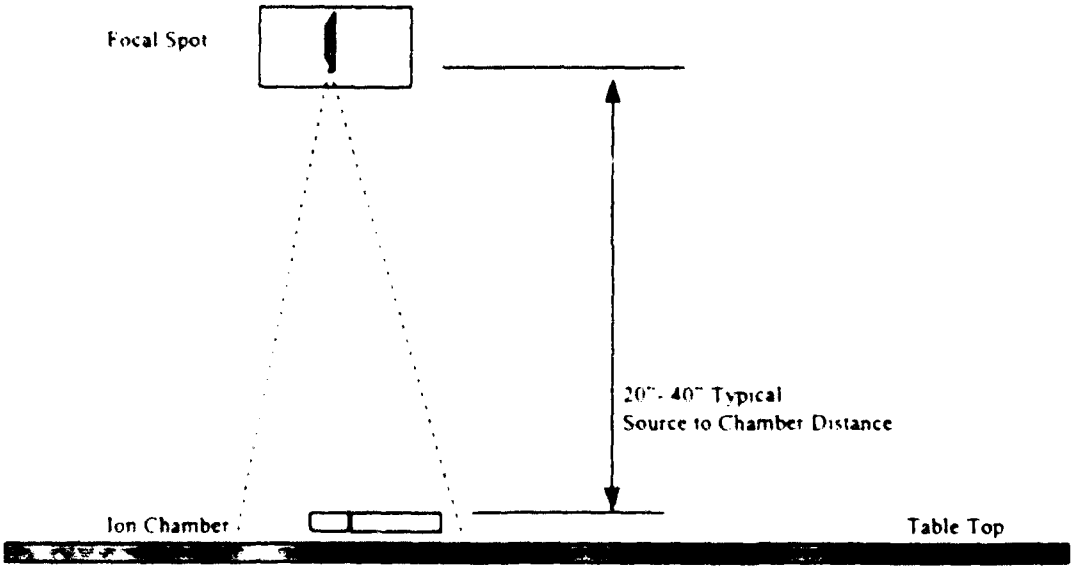

Figure 1. Setup for ESE Measurements in Conventional Radiography

3. Make a series of exposures with a variety of kVp settings at a constant mAs, recording the measured exposure in mR. A typical table of results will include 10 measurements at 10 mAs, with the kVp adjusted through the entire useable range of kVps for the system.. The measured exposure is divided by the mAs to result in a table of kVp verses mR/mAs.

measurements at a given source to chamber distance (SCD). An example of the information gathered is shown in Appendix A.

Interpretation

Since the intensity of x-rays is proportional to the square of the kVp and exposure is proportional to intensity(10), it is a simple matter to generate a quadratic regression of the exposure/mAs data as a function of kVp:

$$\frac{mR}{mAs} = \alpha + \beta kVp + \gamma kVp^2$$

where α, β and γ are constant coefficients determined from a regression analysis. To account for the geometry of an exposure, the inverse square law must be applied to determine the exposure at the entrance of the patient instead of where the ion chamber was positioned during the measurements(11). The distance from the source to the surface of the patient (SSD) is determined by either measuring it directly, or from the source to image (film) distance (SID) less the image to table top distance (ITTD) and the patient thickness (PT), as appropriate. Table 2 provides typical patient thickness and SIDs for a range of common projections.

TABLE 2. Common Projections, and Associated SIDs and Patient Thickness(12)

Projection*	SID (inches)	Patient Thickness (cm)
Chest, AP	72	23
Chest, Lat	72	30
Skull, AP	40	20
Skull, Lat	40	15
Mandible, PA	40	16
Mandible, Oblique	40	16
Cervical SPine, AP	40	13
Ribs, PA	40	20
Shoulder, AP	40	16
Cholecystography, PA	40	23
Thoracic Spine, AP	40	23
Lumber Spine, AP	40	23
Lumbosacral Spine, AP	40	23
Abdomen (KUB), AP	40	23
Barium Enema Sudy, AP	40	23
IVP, Plain Film, AP	40	23
IVP, Tomography, AP	40	23
Pelvis, AP	40	23
Hip, AP	40	21
Thigh, PA	40	17
Knee	40	12
Humerus, AP	40	10
Hand wrist, AP	40	5

* Notes AP =anteroposterior, IVP = intravenous pyelogram., KUB = kidney, ureter, bladder, LAT = lateral, ND = no data, PA = poteroanterior, and SID = source to image distance.

The ESE (free in air) for a given technique and exposure geometry is then calculated as:

$$ESE(mR) = \left[\frac{SCD}{SID - (ITTD + PT)}\right]^2 (\alpha + \beta kVp + \gamma kVp^2) mAs$$

Since most radiographic procedures are phototimed, arriving at the appropriate mAs for a given procedure can be difficult. If the x-ray unit provides an indication of the time of exposure for a given current station, or if the mAs is displayed directly, then this value can be used to determine the ESE. It is important to note that there can be significant variation in phototimed mAs between patients of relatively equivalent thickness(13). Recording an average mAs for a number of patients of the same thickness is the preferred method for arriving at the best estimate of a phototimed ESE.

The use of "equivalent" manual techniques, i.e. the best guess of a manual technique which matches a phototimed procedure, is generally not reliable and should be avoided. Manual techniques should only be employed for ESE determination if they are routinely used. If phototimed mAs data is not available, it can best be determined by the use of phantoms of relevant thickness and composition. The AAPM has recommended the use of a LucAl (lucite-aluminum) phantom developed by the Center for Devices and Radiological Health (CDRH) of the FDA(2). This phantom was used to obtain the NEXT national survey data and has been shown to be equivalent to a 23 cm posteroanterior chest and a 21 cm anteroposterior abdomen or lumbosacral spine(2). Unfortunately these phantoms are not readily obtainable and are expensive. The AAPM has also recommended use of the American National Standards Institute (ANSI) phantoms for the chest and skull and a modified ANSI phantom for the abdomen and lumbosacral spine be used(2). The phantom consists of 12 x 12 x 1 inch (or 10 x 10 x 1) slabs of lucite and various thickness of 1100 type aluminum and is fairly inexpensive. [1] On the other extreme, anthropomorphic sectional phantoms and fully anthropomorphic phantoms are also available. These phantoms provide realistic objects which can be used to obtain mAs and ESE data for most common projection including skull, hand, pelvis, chest, foot, ankle, knee and elbow. Unfortunately, they are very expensive. [2]

Once a suitable phantom is selected for a given procedure, the measurement of phototimed mAs can be performed. The phantom is positioned to simulate the desired procedure and an ion chamber is placed from 0 to 10 cm above the phantom surface. An exposure is then made in AEC mode, with the subsequent response from the chamber recorded. Exposures are then made in manual mode with the ion chamber in the same location and the kVp kept constant. The mAs is changed between exposures until the mAs which produces the same exposure as that obtained in the AEC mode is identified. The shortcoming of this procedure is that the measured ESE at this mAs applies only to an average patient.

To simplify calculation of ESEs, a simple Excel™ V7.0 spreadsheet has been developed, which is included with this report. Details of the calculations used in the Microsoft® Excel spreadsheet and an example output is shown in Appendix A.

Mobile X-Ray

No special considerations are generally required for portable x-ray systems. Assessments of radiation output can be performed in an identical manner to permanently installed units. Again, this data should be readily available from the MERC annual calibration of the system. If

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[1] This phantom is available from Nuclear Associates, Model 76-215 for $460, (516)741-6360.

[2] Sectional phantoms are available from Nuclear Associates, (516)741-6360 and Gammex RMI (608)831-1188. A complete set will typically cost over $15,000.

Mobile X-Ray

No special considerations are generally required for portable x-ray systems. Assessments of radiation output can be performed in an identical manner to permanently installed units. Again, this data should be readily available from the MERC annual calibration of the system. If a separate determination of radiation output is desired, the unit can be positioned inside a conventional x-ray suite, and the patient table used to support the dosimeter. The technicians console area can then be used to make the exposures so that the technicians exposure is As Low As Reasonably Achievable (ALARA). The spreadsheet used to determine patient ESE can be greatly simplified to include only those procedures conducted with the portable unit. A sample worksheet for portable units is included as with the spreadsheet accompanying this report.

Dental Radiography

As with conventional x-ray, annual calibration of dental x-ray systems includes collection of radiation output data for the range of kVps of the system. However, because a limited number of techniques are used for intraoral examinations and panalipse procedures, it is often easier simply to expose a dosimeter to the same techniques used for conventional radiographs. The measured exposure can then be corrected using the inverse square law for the source to patient distance. Again, a sample worksheet has been provided with this report which allows calculation and record of a patients entrance skin exposure from dental procedures.

An area of dental radiography which has not been well addressed is the dose received during panoramic or panalipse procedures. Measurement of the ESE resulting from these procedures requires mounting a dosimeter (ion chamber) physically to the cone aperture so that it remains in the x-ray beam during the entire exposure. The dosimeter is centered in the beam, at a distance from the aperture corresponding to the closest distance an individuals head would be. This is usually two to three inches from the cone tip. Normal exposures are then taken using a range of conventionally used techniques, and the integrated exposure recorded. Unfortunately, there is no published information available against which measured exposures can be compared.

CONVENTIONAL FLUOROSCOPY SYSTEMS, C-ARMS AND DIGITAL FLUOROSCOPY

Fluoroscopic procedures have the potential of causing extremely high patient doses, to the extent that radiation injury results. The FDA has reported 26 cases of radiation injury between 1992 and 1995, specifically burn-like injuries and skin necrosis, for patients undergoing various interventional and therapeutic fluoroscopic procedures(14). The potential for these acute effects, as well as the increased risk of cancer incidence posed by high doses places substantial emphasis on tracking patient dose resulting from these procedures.

Unfortunately, accurate estimation of a patients integrated entrance skin exposure resulting from a given fluoroscopic examination is complicated. Factors such as varying kVp and mAs from automatic brightness controls (ABC), varying fluoroscopic on time, varying numbers of spot films, and varying field sizes and locations all can significantly impact exposures at the patient surface and subsequent organ doses. Instead of determining the integrated ESE, the intent of the JCAHO standards in the case of fluoroscopy is to determine if the exposure *rates* are "reasonable" and within the legal limits specified in Title 21, the Code of Federal Regulations, Part 1020.

Image Intensifier (II) Input Exposure Rates and Exposures

Determination of whether the entrance skin exposure rates are acceptable begins by first establishing whether the exposure rate at the input phosphor is appropriate. This is critical to determining whether the automatic brightness control reference level is set appropriately. For conventional fluoroscopy with a 9" image intensifier without grid, this should be less than 4 mrem/min (or 2.2 μR/frame) and less than 2 mR/min (1.1 μR/frame) for low dose rate fluoroscopy(15). Other image intensifier field sizes will have values which scale inversely with the area. The measured values should also be compared to the manufacturers specifications. If these reference values are not exceeded, then there is good confidence that the system is capable of reasonable low entrance exposure rates, without sacrificing low contrast resolution. On the other hand, if the exposure rate is too low the image will be noisy and low contrast performance will suffer.

Similarly, the input phosphor exposures necessary to produce conventional spot films, photofluoroscopic spot films and cine images with adequate image quality and density while minimizing staff and patient exposures should be measured. The exposure of conventional spot films is determined by film/screen speed, the kVp and the presence of a grid. The exposure of spot film cameras (photofluorospot films) and cine cameras that capture an image from the image intensifier is determined by these characteristics as well as the aperture of the camera-lens system. The use of small apertures requires higher patient exposures and produces lower noise images than the use of larger apertures. Typical input phosphor exposures for spot films using an American National Standards Institute (ANSI) 21 cm phantom should be in the range of 50 to 200 μR/image (dependent on image intensifier size) to produce film densities of about 1.2± 0.15(16). For conventional spot films, the film density should be uniform from side to side, while the density of PFS images will likely decrease towards the edges. For cine, adequate film exposures are required to produce high quality, relatively low noise images necessary for cardiac diagnosis. Because of the large number of frames which may be required and due to the fluoroscopy on time for catheter placement, both patient and staff exposures can become significant(17). In general, approximately 15 μR/frame is required at the entrance to the image intensifier for adequate cine studies using 9" mode II and 35 μR/frame using 6 inch mode II(18).

Measurement of II entrance exposures for digital fluoroscopic systems and digital subtraction angiography (DSA) systems is similarly important. The measured exposures should agree with the manufacturers recommended input exposures to verify the unit is functioning within normal limits. In general, measured exposures for DSA should not very significantly from those in Table 3.

TABLE 3. Typical Entrance Exposure Values for DSA (μR/frame)(19)

Mode	Image Intensifier Input Size		
	6"	9"	12"
Pulsed Intra-arterial	220-550	100-250	90-150
Pulsed Intravenous	1100-2200	500-1000	300-600
Continuous	2-20	1-10	0.5-5

Measurement Methods: Input Phosphor Exposure Rates:

Equipment

The measurement of image intensifier input rates requires a dosimeter, such as those described in Chapter 2, and use of a large volume (high sensitivity) ionization chamber because of the much smaller exposures and exposure rates associated with the x-ray beam transmitted through the patient. The ion chamber should also be capable of measuring the exposure rate for a pulsed x-ray system, as is common for cine operations. The first four dosimeter packages listed in Chapter 2 include a 100 cc or 150 cc chamber to perform these measurements.

A patient equivalent phantom, typically composed of 8 to 10 1" thick blocks of polymethyl methacrylate (PMMA), with each block 10 x 10 or 12 x 12 inches. A 7 slice phantom is available from Nuclear Associates for $460, and additional slices can be purchased at a nominal cost.

Procedures

The input-phosphor exposure rate (IPER) and input phosphor exposure (IPE) is measured using a geometry as shown in Figure 2. Ideally, the high sensitivity ionization chamber used is physically separate from the electronics package to minimize perturbations in the radiation field. Separated chambers are also more readily positioned against the image intensifier. The 21 cm thick ANSI phantom (8 1" Lucite slabs with 3 mm Al) is placed on the table top, the grid is carefully removed and the ion chamber is placed carefully in the center of the field as close to the image intensifier as possible. To not interfere with normal operation of the ABC in this measurement, normal collimation is used; one does not "cone down". Distances are noted so that the measured input phosphor rate can be referenced to the input-phosphor plane. The measurements are repeated for each II mode, with and without a high level control, at kVps typical for the abdomen.

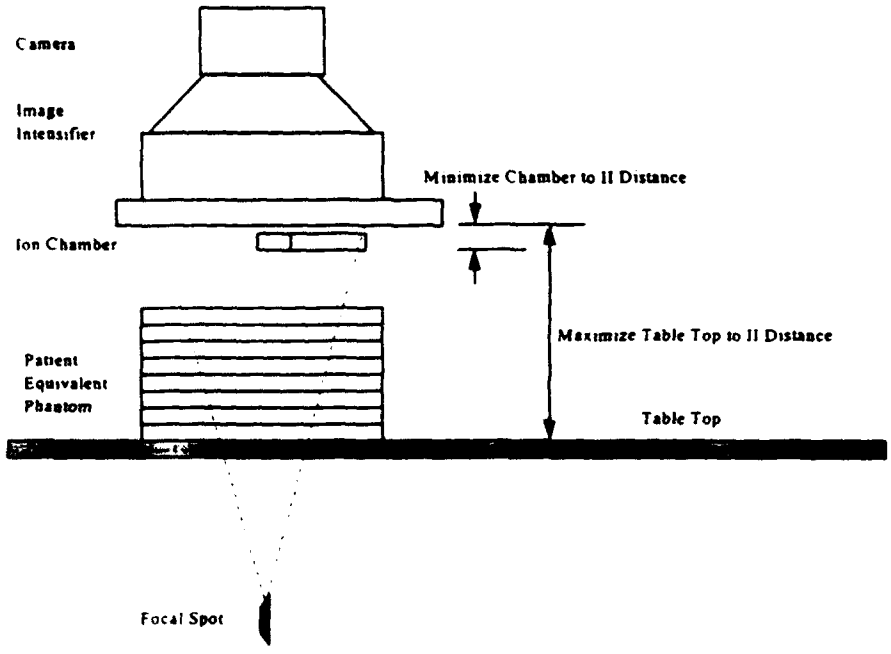

Figure 2. Setup for IPER Measurements

Assessment of the IPE from spot films, PFS and cine occurs with a similar set-up. However, for these exposures the grid should be in-place, and ideally, the ion chamber is placed behind the grid. A simple spreadsheet has been developed to allow tracking of this data. It is included with the spreadsheet provided with this report and shown in Appendix B.

Entrance-Skin-Exposure Rates and Spot Film Exposures

Once phosphor entrance exposure rates are determined to be reasonable, the patients ESE can be assessed. Two specific tests should be performed: 1) determining the maximum entrance skin exposure to insure it does not exceed federal limits, and 2) determining the ESE for typical patient thickness and image intensifier modes, both with and without the use of grids for JCAHO dosimetry purposes.

Standard fluoroscopic exposure rates for an average size patient can range from 1 to 5 R/min. However, for obese patients or for lateral and oblique projections of a normal patient, where limits are not set correctly on tube output, exposure rates can exceed 20 to 30 R/min, with a commensurate increase in exposure to the staff. Consequently it is essential to check the maximum fluoroscopic exposure rate regularly. Table 4 summarizes the legal requirements on maximum exposure rates at the table top:

TABLE 4. Regulatory Limits on Maximum Entrance Skin Exposures in Fluoroscopy(20)

High Level Control (HLC)?	Automatic Brightness Control (ABC)	Manufactured After 19 May 95	Exposure Rate Limit
No	No		5 R/min
No	Yes		10 R/min
Yes	No	No	5 R/min with HLC not activated, no limit if activated
Yes	Yes	No	10 R/min with HLC not activated, no limit if activated.
Yes	No	Yes	5 R/min with HLC not activated, 20 R/min if activated
Yes	Yes	Yes	5 R/min with HLC not activated, 20 R/min if activated

Clinical table top entrance skin exposure rates will vary considerably depending on patient thickness, system age, design, kVp and filtration. Most fluoroscopic systems should be able to obtain good quality images using a 21 cm patient equivalent phantom with ESEs of 2 to 3 R/min for 6" image intensifiers and 1.5 to 2.5 R/min for 9" image intensifiers, measured without a grid. The entrance exposure rates for systems with the grid in place will be about 1.5 to 2 time higher. Other size intensifiers will have ranges which scale inversely to their entrance phosphor area. The use of grids can be eliminated for fluoroscopy as well as for PFS filming with a resultant exposure reduction by a factor of two(21). Table 5 provides typical ESEs for conventional spot films, photofluorospots and cine operations, again using a 21 cm PEP for a range of system kVps.

TABLE 5. Typical Patient Entrance-Skin-Exposures for Spot Films and Cine

	Spot Films[b]	Photofluorospot (PFS) Films w/o Grid		w/ Grid		Cine	
kVp	(mR)[c]	6" II (mR)[c]	9" II (mR)[c]	6" II (mR)[c]	9" II (mR)[c]	6" II (μ R/frame)[d]	9" II (μ R/frame)[d]
60	450	95	50	170	95		
70	265	65	35	105	60	14	17
80	171	50	30	80	45	11	17
90	145	40	25	65	40	9	18
100	130	40	25	60	35		

[a] Data originally from Joel Gray, Mayo Clinic, Reproduced from NCRP Report 99.
[b] Taken with 300 speed film, with grid in place. Film densities.
[c] Measurements made with a 21 cm patient equivalent phantom, 80 cm source to image distance, and a 15 cm object to image distance with a 10:1 grid, and a 3ϕ generator with an HVL of 3.2 mm at 80 kVp. Spot film densities were between 1.0 and 1.3, PFS densities were between 0.8 and 1.2. Screens used were Kodak Lanex Medium and TML film. Image intensifier exposures were 240 μR for a 9" II and 150 μR for a 6" II.
[d] Measurements made with a 21 cm patient equivalent phantom, 85 cm source to image distance, and a 15 cm object to image distance with a 8:1 grid, and a 3ϕ generator with an HVL of 3.2 mm at 80 kVp. Film densities were between 0.8 and 1.2. Single frame exposure rates at image intensifier were 15 μR/frame for a 9" II and 35 μR/frame for a 6" II.

Measurement Methods: Maximum Entrance-Skin-Exposure Rates

Equipment

An electronic dosimeter, as discussed previously using the standard ionization chamber for diagnostic measurements (10 cc to 15 cc volume).

Two 3 mm thick sheets of lead, approximately 8" on a side, and spacers to support the sheets above the table-top.

Procedure

In this arrangement, lead sheets are elevated above the table using spacers such that the ionization chamber can be positioned on the table surface. Some patient equivalent phantoms come with a horseshoe shaped lucite spacer 2" thick. This or an equivalent foam or plastic spacer can be used to raise the phantom 2 to 3 inches above the table surface. The II is positioned 12" above the table top. So as not to interfere with normal ABC operations, normal collimation is again used. Two 8" (20 cm) square sheets of lead, 3 mm thick, are positioned on top of the support stand (Figure 3).

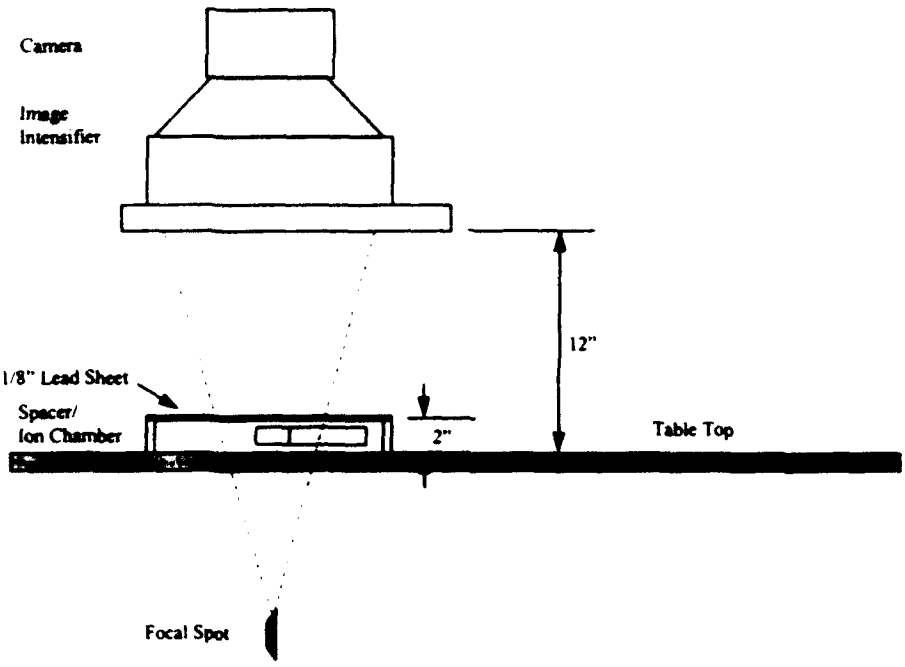

Figure 3: Set-up For Measure Maximum Entrance-Skin-Exposure Rate

Fluoroscopic exposures are now made in the various operating modes. In manual modes, techniques are manually ramped to the highest possible output, and in ABC mode the system will automatically drive techniques to a maximum level. It should only be necessary to measure to measure maximum exposure rates in normal mode, as the values obtained in magnified modes are slightly smaller due to less backscatter from the phantom. The maximum outputs in each mode are recorded and compared to those in Table 3-3 for compliance. This test should be carried out at least every 6 months and whenever service work is performed on the fluoroscopic system(22).

Measurement Methods: Patient Entrance-Skin-Exposure Rates

Equipment

An electronic dosimeter, as discussed previously using the standard chamber for diagnostic measurements (10 cc to 15 cc volume).

A patient equivalent phantom (21 cm lucite, in 1" thick slices).

Procedures

In this arrangement, the lead sheets are replaced by the 21 cm patient equivalent phantom, again elevated above the table using spacers such that the ionization chamber can be positioned on the table surface. The geometry for the measurement is shown in Figure 4.

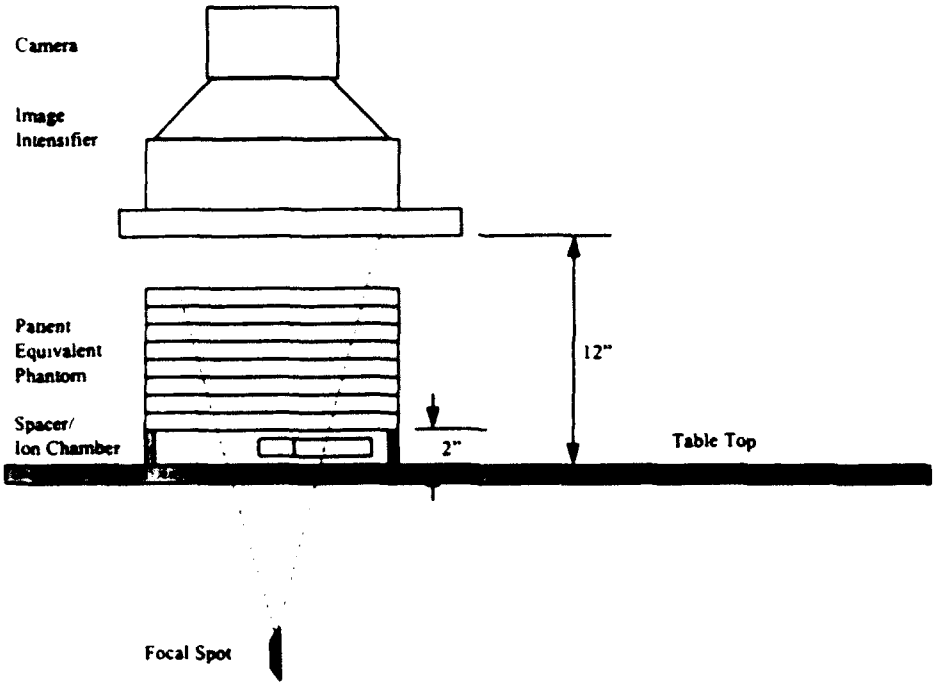

Figure 4: Setup for Measuring Patient Entrance-Skin-Exposure Rate, and Patient Exposures from Spot Films, PFS Films and Cine

To provide data for a range of patient thickness, the PEP can be adjusted to provide several thickness, such as 11, 16 and 21 cm. Fluoroscopic exposures with and without grids in the available operating modes of the II can then be performed. Similarly, the ESEs for conventional spot films, PFS and cine exposures can be determined. For each of these radiographic methods, ESEs should be assessed for a several phantom thickness, with and without grid, with a range of kVps. Results are recorded on the appropriate section of the spreadsheet, included on disk and shown in Appendix B.

C-ARMS

The dosimetry for these mobile fluoroscopic systems is assessed in a similar method to conventional stationary systems. Usually, the reduced complexity of the image intensifier and x-ray tube allows determination of the IPERs and ESE rates much more directly than fixed units. A unique aspect of these systems however is that the minimum source to skin distance is only 12", as compared to 15" for stationary tubes. Because this distance is usually established by a removable spacer attached to the collimator, it is not uncommon to find the spacer removed so that the unit could be positioned and operated more easily for certain operations. If this practice becomes routine, or if the spacer becomes lost, patient exposures could be significantly increased due to the reduced source-to-skin distance. Thus assessment of ESE rates for these systems should include verifying that any necessary spacer is present and used routinely. As with portable diagnostic x-ray units, the measurement of IPERs and ESE rates is best performed within an x-ray suite using the patient examination table for supporting the necessary phantoms.

FDA Public Health Advisory: Avoidance of Serious X-Ray-Induced Skin Injuries to Patients During Fluoroscopically-Guided Procedures(23)

The procedures described above will assist in assuring that a fluoroscopic system produces reasonable patient exposures. However, these assessments are of limited value in determining the integrated skin exposure and dose received by a given patient during a given fluoroscopic examination. Extremely high doses can still occur if long fluoroscopic times are used in conjunction with large numbers of radiographs, particularly for obese patients. To avoid skin doses which may result in acute injury, the FDA suggests that facilities performing fluoroscopically-guided procedures observe the following principles:

1. Establish standard operating procedures and clinical protocols for each specific type of procedure performed. The protocols should address all aspects of the procedure, such as patient selection, normal conduct of the procedure, actions in response to complications and consideration of limits on fluoroscopy exposure time

2. Know the radiation dose rates for the specific fluoroscopic system and for each mode of operation used during the clinical protocol. These dose rates should be derived from measurements performed at the facility.

3. Assess the impact of each procedure's protocol on the potential for radiation injury to the patient

4. Modify the protocol, as appropriate, to limit the cumulative absorbed dose to any irradiated area of the skin to the minimum necessary for the clinical tasks, and particularly to avoid approaching cumulative doses that would induce unacceptable adverse effects. Use equipment which aids in minimizing absorbed dose.

5. Enlist a qualified medical physicist to assist in implementing these principles in such a manner so as not to adversely affect the clinical objectives of the procedure

Physicians should know that radiation-induced injuries from fluoroscopy are not immediately apparent. Other than the mildest symptoms, such as transient erythema, the effects of the radiation may not appear until weeks following the exposure. Physicians performing these procedures may not be in direct contact with the patients following the procedure and may not observe the symptoms when they occur. Missing the milder symptoms in some patients can lead to surprise at the magnitude of the absorbed doses delivered to the skin of other patients when more serious symptoms appear. For this reason, the FDA recommends that information be recorded in the patient's record which permits estimation of the absorbed dose to the skin. Patients should also be advised to report signs and/or symptoms of radiation induced injury to their attending physician.

The Safe Medical Devices Act of 1990 (SMDA) requires hospitals and other user facilities to report deaths, serious illnesses and injuries associated with the use of medical devices. Follow the procedures established by your facility for such mandatory reporting. Practitioners who become aware of any medical device related adverse event or product problem/malfunction should report to their Medical Device User Facility Reporting person. If it is not reportable under the SMDA, it may be reported directly to MedWatch, the FDA's voluntary reporting program. Submit these reports to MedWatch, Medical Product Reporting Program, by phone at 1-800-FDA-1088 (also call for MedWatch information); by FAX at 1-800-FDA-0178; by modem

at 1-800-FDA-7737; or by mail to MedWatch, HF-2, Food and Drug Administration, 5600 Fishers Lane, Rockville, MD 20857.

For facilities concerned about patient doses received during interventional fluoroscopic procedures, the most accurate means of assessment is through personnel dosimetry. Special thermoluminescent dosimeters (TLDs) are available through the radiation dosimetry branch of Armstrong Laboratory (AL/OEBZ, DSN-240-3486) for conducting studies of patient dose. The dosimeters are radiographically invisible and can be adhered to the patient using a simple band-aid.

COMPUTED TOMOGRAPHY (CT) DOSE ASSESSMENT

Computed tomography uses highly collimated x-ray beams which circumscribe the patient. Since this manner of exposure varies dramatically from conventional x-ray, dose distributions delivered to the patient will very greatly from conventional x-ray doses. Whereas conventional x-ray uses the ESE as a dose parameter, CT doses are reported as the computed tomography dose index (CTDI) or the closely related multiple scan average dose (MSAD). This section presents a description of these dose parameters specific to CT, and some rules of thumb are presented on how dose is affected by various scan techniques. Finally, equipment and methods used to measure CTDI and MSAD for JCAHO compliance purposes is discussed.

Dose Parameters Specific to CT

The data necessary for tomographic imaging is acquired by exposing the patient to a highly collimated fan-beam of x-rays and measuring the x-ray intensity which exits from the patient. One "slice" of the patient can be reconstructed by measuring this transmission data for a 180° scanning arc, but most system use 360° scan rotations or more. The thickness of the slice is determined by the collimation of the beam, and is denoted "T". If you were to examine the dose *profile of the x-ray beam along the scanners central axis* (the "z" direction), it is observed that there are "tails" on the dose distribution due to beam divergence, penumbra and scatter. A schematic of a CT system and a typical dose distribution profile for a single scan is shown in Figure 5.

Determining patient dose in CT is complicated because most scans performed in CT require more than one slice of the patient to be acquired. When adjacent slices are scanned, the dose to any one slice is increased by contributions from other slices. The magnitude of the increase depends on the thickness of the slice, the number of slices, the slice separation, and the dose characteristics of the single-scan dose profile.

By convention, the dose typically assessed for routine quality control and dosimetry purposes is the Multiple Scan Average Dose (MSAD), measured by taking a single scan of a cylindrical phantom into which is inserted a pencil type ion chamber(24). The MSAD is defined as:

$$MSAD = \frac{1}{I}\int_{-\frac{I}{2}}^{\frac{I}{2}} D_{N,I}(z)dz \qquad (1)$$

where $D_{N,I}(z)$ is the dose as a function of position, z, for a constant x,y within the scan plane for a multi-slice scan profile with N-slices separated by a constant distance between slices equal to I. The concept is shown graphically in Figure 6.

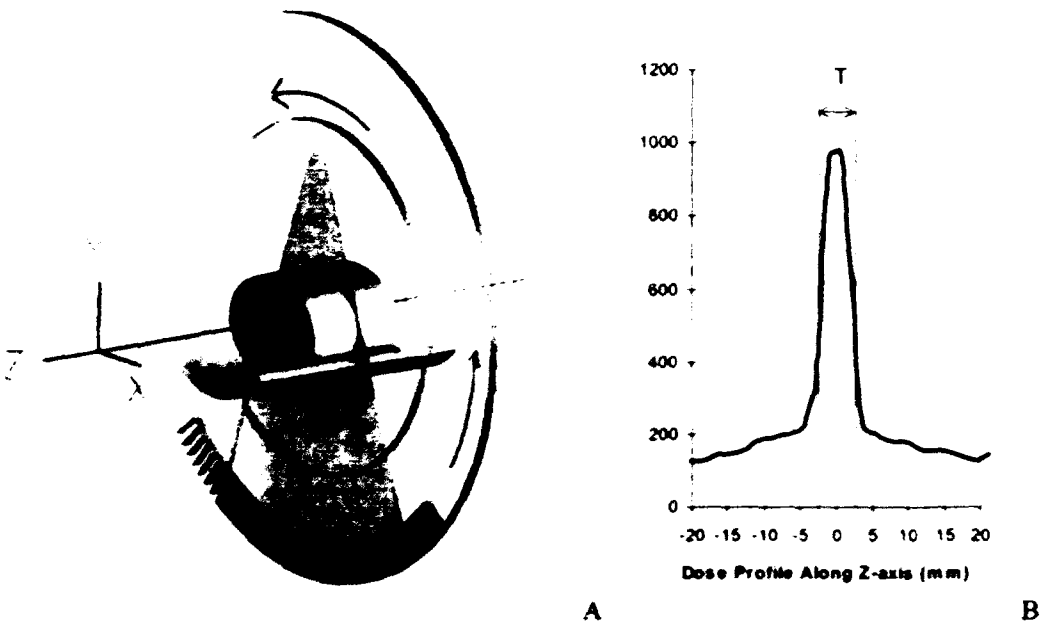

Figure 5: Schematic of CT Scanner and Z-Direction Dose Profile. A) A fan beam of radiation passes through the patient in the transverse direction. The beam is then intercepted by a detector array. The data to reconstruct a slice of the patient is obtained by rotating the x-ray source and detector array around the patient 180° or 360°. B) The dose profile along the patient (Z direction) has tails due to scatter, beam divergence and penumbra (Method: 16 cm phantom, 120 kVp, 300 mAs, GE 9800)

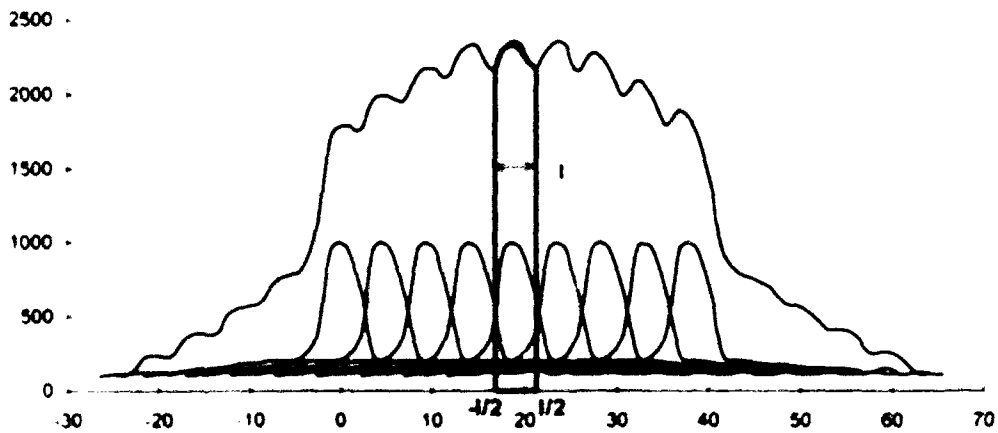

Figure 6: The Multiple Scan Average Dose (MSAD), equal to the integrated dose received over region I. the slice separation distance. It is observed how the overlap of multiple slice scan results in an increase in the MSAD

A similar dose descriptor proposed by the CDRH for CT dosimetry is the Computed Tomography Dose Index (CTDI). This is defined as:

$$CTDI = \frac{1}{T}\int_{-\infty}^{+\infty} D_1(z)dz \qquad (2)$$

where $D_1(z)$ is the dose as a function of position along the z-axis (the single-slice scan dose profile) for a constant x,y in the scan plane, and T is the slice thickness. Visually, the CTDI is the integral of the single scan dose profile, as seen in Figure 4B, divided by the slice thickness, T.

It has been shown that the area under the multiple-slice dose profile over a width T in the center of the scan is equal to the total area under a single scan dose profile (provided the first and last slices of the multiple slice series do not contribute much dose to the central slice of the series). Thus, when the slice thickness equals the slice separation (I=T), the CTDI is equal to the MSAD. Further, when the slice thickness doses not equal the slice separation, the CTDI is related to the MSAD by:

$$MSAD = \frac{T}{I} CTDI \qquad (3)$$

This expression allows the MSAD to be determined easily from a measured CTDI for a wide array of scans. The CTDI is easily assessed using a pencil-type ion chamber inserted into an appropriate phantom.

Another important dosimetry concept is the $CTDI_{Reg}$, which is often used interchangeably with the CTDI. Manufacturers of computed tomography systems must provide the user measured $CTDI_{Reg}$ data for all new installations(25). The CDRH has formally defined this quantity as:

$$CTDI = \frac{1}{nT}\int_{-7T}^{+7T} D(z)dz \qquad (4)$$

where z is the position along a line perpendicular to the tomographic plane, D(z) is the dose at position z, T is the nominal tomographic slice thickness and n is the number of tomograms produced in a single scan. The integration is over a length equal to 14 adjacent slices, rather than an infinite distance in the definition of CTDI. It has been shown that the MSAD and $CTDI_{Reg}$ could become equal for a series of 12 to 20 slices. However, the $CTDI_{Reg}$ may significantly underestimate the MSAD, particularly for thin slices.

Measured Dosimetry for Conventional CT Systems

There has been considerable study of the dose resulting from CT scanners. The most comprehensive is that conducted by the CDRH during two nationwide surveys. McCrohan et.al. have reported on the summary results of 250 scanners to determine the average dose from typical adult head procedures(26). The MSAD was typically in the range of 22 to 68 mGy (2.2 to 6.8 rad). The major results of the study are summarized in Table 6:

TABLE 6. Standard Techniques and Dosimetry for several CT systems with 10 or more Surveys in the CDRH Database

Parameter	GE 8800	GE9800	Picker 600	Picker 1200	Siemens DR	Technicar e 2060
kVp	120	120	120	130	125	120
Slice Thickness (T)	10 (100%)	10 (95%)	10 (76%)	10 (60%)	8 (88%)	10 (95%)
Packing Factor (T/I)	1	1	1	1	1	1
No. of Slices/ Procedure	10 (10%) 11 (15%) 12 (58%) 13 (12%) 14 (4%) >14 (2%)	10 (5%) 11 (31%) 12 (38%) 13 (5%) 14 (12%) >14 (9%)	10 (6%) 11 (12%) 12 (53%) 13 (12%) 14 (6%) >14 (12%)	10 (0%) 11 (16%) 12 (28%) 13 (20%) 14 (4%) >14 (32%)	10 (5%) 11 (0%) 12 (5%) 13 (10%) 14 (40%) >14 (35%)	10 (0%) 11 (5%) 12 (56%) 13 (4%) 14 (10%) >14 (15%)
Avg. mAs	568	395	297	310	475	357
Avg Surface MSAD (rad)	3.2 ± 0.9	5.2 ± 1.7	5.0 ± 1.4	5.4 ± 1.2	3.4 ± 0.5	6.8 ± 1.7
Avg MSAD (rad/100mAs)	0.6 ± 0.2	1.3 ± 0.2	1.8 ± 0.6	1.8 ± 0.5	0.7 ± 0.1	2.0 ± 0.7

For CT imaging of the trunk, a study by Mini et.al. summarizes the mean organ doses received by 21 organs resulting from thoracic, abdominal and pelvic examinations(27). This study was conducted using thermoluminescent dosimeters (TLDs) inserted into an anthropomorphic phantom to directly estimate organ dose resulting from a third generation scanner (Somatron Plus, Siemens Medical Systems). The following range of doses were observed in this study: the skin received 22-36 mGy (2.2 to 3.6 rad); the lungs, less than 1 - 18 mGy (0.1 - 1.8 rad); the kidneys 7-24 mGy (0.7 - 2.4 rad) and the ovaries, less than 1 - 19 mGy (0.1 - 1.9 rad). The techniques and subsequent organ doses found during this study are shown in Table 6.

Factor Affecting Patient Dose

In general, the effective radiation dose received from a CT examination is somewhat higher than that received during an equivalent radiographic examination. A CT image of the head requires 1 to 2 rad and abdominal images requires 3 to 5 rad. This is considerably higher than the doses shown in Table 2-1. The relationship between resolution and dose for CT imaging is expressed as:

$$D = \alpha \frac{s^2}{e^3 TB}$$

where D is the patient dose, s is the signal to noise ratio (contrast resolution), e is the spatial resolution and T is the slice thickness, B is the transmission through the patient and α is a constant. From this equation the following observations can be made:

TABLE 7. CT Techniques and Dosimetry Results for Study of Trunk Organ Dose

Parameters	Thorax	Abdomen	Pelvis
kVp	137	120	120
Slice Thickness (T)	10	10	10
Packing Factor (T/I)	1-0.666	1-0.666	1-0.666
No. of Slices/ Procedure*	25,(35),45	25,(35),45	25,(30),35
Average mAs/slice	150	210	340
Uppermost Position (Vertebrae)*	T-1,(T-2)	T-8,(T-9),L-3	L-2,(S-1),
Lowermost Position (Vertebrae)*	(T-12),L-4	(L-5),S-2	(N4)
	(dose in rads)†	(dose in rads)†	(dose in rads)†
Skin	2.21	3.03	3.61
Bone Marrow	0.047	0.059	1.1
Testes	0.003	0.016	0.83
Ovaries	0.017	0.16	1.89
Uterus	0.016	0.15	1.93
Bladder	0.016	0.14	1.97
Colon	0.42	2.08	2.07
Small Intestine	0.15	1.53	2.58
Kidneys	0.68	2.41	1.58
Liver	1.32	2.13	0.30
Spleen	1.37	2.10	0.32
Pancreas	1.05	1.59	0.36
Stomach	1.22	1.83	0.28
Lung	1.76	0.70	0.085
Breast	2.03	0.43	0.052
Esophagus	1.38	0.51	0.064
Thyroid Gland	0.56	0.028	0.006
Brain	0.037	0.005	0.003
Lenses	0.037	0.005	0.003

* Values in parenthesis are the average values used for the actual dose assessment.
† Dose does not include that resulting from scout (topogram).

a. To improve the signal to noise ratio by two, the dose must be increased by a factor of four.

b. To improve the spatial resolution by two, the dose must be increased by a factor of eight.

c. To decrease the slice thickness by two, while maintaining the same image quality, the patient dose must be doubled.

d. To decrease the slice thickness by two and the pixel size by two, while maintaining the same image quality, the patient dose needs to increased 16x.

Since the transmission through the patient depends exponentially on patient thickness, doubling the patient thickness will decrease transmission to B^2. This has a dramatic effect on the dose required to keep image quality constant. For example, assume a thin patient torso allows 5% x-ray transmission. A large patient having twice the anatomical thickness will

require a 20 fold increase in dose. This is one reason why larger pixel sizes are typically used for body scans as compared to head scans.

Measurement Method

Equipment

The standard protocol for measuring the MSAD uses two standardized phantoms: a 16-cm and 32-cm diameter acrylic cylinder that simulates the adult head and torso. A series of 1 cm holes are located parallel to the axis of the cylinder, with typically four around the periphery of the cylinder and one along the center. Phantoms are available from Radcal Corp, Model 20CT6 head phantom and Model 20CT14 body phantom for a total of $2060, or Nuclear Associates, Victoreen Inc, Model 76-414 head dose phantom and Model 76-415 body dose phantom (with case) for $1925.

The phantom requires use of a pencil type ion chamber (typically less than 1 cm in diameter and 10 cm long) with an active volume of about 3 ml. Several vendors produce these chambers, which are compatible with their electronic dosimeters for measuring conventional radiographic and fluoroscopic exposures. Specifically, the following ion-chambers are available:

a. Nuclear Associates, Victoreen Inc, Model 30-301-1000, $1155, designed to be read out by the NERO, 4000M+, and RadCheck electrometers.

b. Radcal Corp, Model 10X5-3CT, $950, for use with 1000, 3000 and 9000 series monitors and the 20X5-3CT, $1095, for use with 2026, 9010 or 9015 series monitors.

c. Keithley Radiation Measurements, Model PC-4P, $1180, designed for use with its 35050A dosimeter.

Procedure

1. Position the head (16 cm) phantom on the patient couch and center the phantom in the scan field. One of the surface holes should be positioned to where the dose is the maximum obtainable at the 1 cm depth. The will typically be in the anterior position. The longitudinal centering of the phantom can be done by taking several scout images, and centering on the overall phantom. The rod inserts for the phantom have small holes in their centers which allow for precise positioning of the phantom.

2. The ion chamber is inserted into the center of the phantom, with all other holes blocked by acrylic rods. Exposures are made for multiple conditions of the operating scanner for head scans. These will include: kVp, mAs, filtration, scan field sizes, slice thicknesses, and 360° scan or overscan. The procedure is then repeated with the dosimeter moved to the surface locations of the phantom. Each time the phantom is moved, the remaining holes are blocked with the lucite rods. Ideally, all five positions dosimeter positions are assessed in this fashion. Practically speaking, assessing the dose in the center and maximum surface location within the phantom is normally adequate.

3. These first two steps are then repeated for the abdominal (32 cm) phantom.

4. The measured exposure for each phantom, dosimeter position and technique is the used to calculate the CTDI as follows:

$$CTDI = \frac{f - factor \times CF \times \text{Chamber\_Reading} \times l}{\text{T}}$$

where the f-factor is the conversion factor from exposure in air to absorbed dose in a medium (i.e. tissue), CF is the correction factor for the chamber reading to account for energy response of the chamber, the chamber reading is that displayed after the scan in mR, l is the active length of the chamber in mm (typically 100), and T is the slice thickness in mm. The exposure to dose conversion factor is in turn calculated as:

$$f = 0.869 \frac{rad}{R} \frac{\left(\frac{\mu_{en}}{\rho}\right)_{PMMA/Tissue}}{\left(\frac{\mu_{en}}{\rho}\right)_{air}}$$

where f and C are typically chosen for an effective x-ray energy of 70 keV, which is typical for most CT examinations. The f-factor used by manufacturers in reporting the $CTDI_{Reg}$ is for the dose to acrylic (PMMA) rather than tissue. For the range of kVps typically employed in computed tomography, the f-factor is 7.8 mGy/R (0.78 rad/R)(28). The following table provides f-values for a range of CT energies for tissue, water and bone. An f-factor of 9.4 mGy/R (0.94 rad/R) is usually acceptable for tissue at CT energies.

TABLE 8. f-values for a typical range of effective diagnostic x-ray energies(29). The values for 70 keV are typically suitable for computed tomography

Energy (keV)	Water (rad/R)	Muscle (rad/R)	Bone (rad/R)
10	0.902	0.918	3.57
15	0.892	0.919	3.99
20	0.886	0.920	4.26
30	0.883	0.922	4.44
40	0.890	0.927	4.20
50	0.905	0.935	3.64
60	0.921	0.942	2.97
70	**0.932**	**0.948**	**2.47**
80	0.947	0.953	1.97
100	0.958	0.957	1.46

If the slice thickness T, is equal to the slice separation I, the MSAD is the equal to the CTDI. If the two values are different, equation three is used to calculate the MSAD.

A spreadsheet has been developed to simplify the data interpretation and storage of results, it is included with this report and a sample is shown in Appendix C. Phantom dosimetry studies should be measured semiannually, and there should be less than a ±20% annual variation in the measurements(30).

CT has the potential of delivering very high doses, particularly if long scanning times and overlapping slices are used. Any procedure that results in a dose in excess of 10 rad (100 mGy) should be investigated to determine if techniques can be altered to reduce dose and still provide a suitable clinical image.

MAMMOGRAPHY DOSE ASSESSMENT

Since passing of the Mammography Quality Services Act (MQSA) in 1992, breast entrance skin exposure and mean glandular dose must be assessed on an annual basis by a qualified medical physicist. The following summarizes the American College of Radiology procedures(31) for assessing breast dose in order to meet the regulatory requirements of this act, and stated in 21CFR900.12 (e)(5)(vi).

Measurement Method

Objective

To measure the typical entrance skin exposure for an average patient (approximately 4.2 cm compressed breast thickness - 50% adipose, 50% glandular composition) and to calculate the associated average glandular dose. [Note: Since the test procedure is normally carried out in the AEC mode, proper functioning of the AEC is assumed and should be verified.]

Equipment

An ionization chamber and electrometer calibrated at mammographic x-ray beam energies (calibration factor constant to within ±1% over the HVL range from 0.2 to 0.5 mm Al). Most of the electrometers/dosimeters listed in Chapter 2 can be used for mammographic exposure measurement, however, a thin window ionization chamber is necessary to measure the low-energy spectrum from mammography systems. Specific chambers (matched to there appropriate electrometer) include:

1. Nuclear Associates, Victoreen Inc, Model 06-529, $590, designed to be read out by the NERO, 4000M+, and RadCheck electrometers.

2. Radcal Corp, Model 10X5-6M, $650, for use with 1000, 3000 and 9000 series monitors and the 20X5-6M, $875, for use with 2026, 9010 or 9015 series monitors.

3. Keithley Radiation Measurements, Model 96035B ion chamber, which is included with its 35050A dosimeter.

4. Gammex RMI, Model FFC-22, designed for use with its Model 242 full function meters.

A mammographic phantom, equivalent to approximately 4.2 cm compressed breast tissue-50/50 composition at screen-film energies. They can be acquired from either Nuclear Associates, Model 18-220 Mammographic Phantom for $550, or Radiation Measurement, Inc., Model 156 Mammographic Phantom for $590.

Also required is a mammographic cassette loaded with mammography film (the film is not processed or reviewed).

Procedure

1. Having verified that the AEC is functioning properly, prepare the mammographic imaging system for operation in the imaging mode (e.g., contact, grid) and with the image receptor size (e.g., 18 cm by 24 cm) most commonly used for clinical imaging. This step includes appropriate field limitation for the imaging mode and image receptor size to be used. Record the conditions on the spreadsheet provided with this report (and shown in appendix D).

2. For mammographic imaging systems with a variable source-to-image receptor distance (SID), adjust the system to the SID most commonly used for mammographic imaging and record the SID on the data form.

3. Position a loaded cassette (of the type and size consistent with the imaging mode selected in Step 1) in the image receptor holder assembly.

4. Select the density control setting on the automatic exposure control (AEC) that is normally used clinically for an average patient. Position the mammographic phantom on the cassette holder assembly at the position which would normally be occupied by the patient's breast (laterally centered in the x-ray field with one edge coincident with the chest wall edge of the cassette holder assembly). For systems that provide multiple positions for the AEC sensor(s), position the sensor(s) under the center of the phantom. Make sure that the mammographic phantom completely covers the active area of the AEC sensor.

5. Position the ionization chamber in the x-ray field beside the mammographic phantom, centered 4 cm in from the chest wall edge of the image receptor and with the center of the chamber level with the top surface of the phantom. Assure that the entire chamber is exposed and that its radiographic shadow does not overlap the active area of the AEC sensor.

6. Secure the chamber position and do not change the position of the chamber during the following measurements.

NOTE: Mammographic imaging systems have a significant x-ray intensity gradient in the x-ray field along the anode-cathode direction. Maintaining a constant chamber position during measurements is critical. When measurements are to be compared to others made previously, it is also critical that the original measurement position be re-established as closely as possible.

7. Position the compression device in the x-ray beam, just in contact with the phantom and chamber, as shown in Figure 7.

8. Select the kVp at which the system is normally used clinically and record the kVp setting on the data form. If phototiming (AEC) is normally used, prepare the unit for operation in the AEC mode. (If only manual control is available and mA is independently selected choose the mA at which the system is used clinically and record this value. On some units, mA may only be "selected" by choosing different focal spot sizes or kVp stations. If exposure time is independently selected, choose the exposure time normally used clinically and record the exposure time. If only mAs can be selected, choose the mAs normally used clinically and record this mAs value.)

9. Make an exposure and record the measured exposure.

10. Repeat Step 9 until a total of four exposures have been recorded. There is no need to change the cassette or film between exposures.

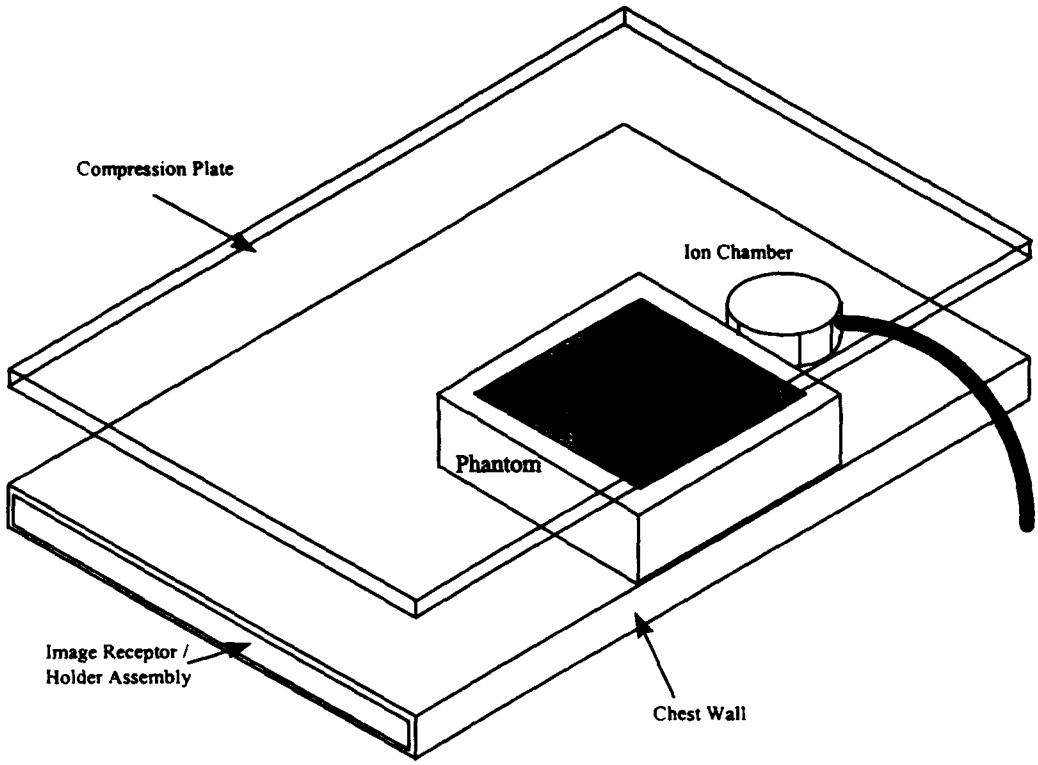

Figure 7: Schematic of placement of the phantom and ionization chamber for measurement of breast entrance exposure. The center of the ionization chamber should be at the same height as the top surface of the phantom.

11. Repeat the procedure at two other clinically utilized kVp's (assure that HVL values have been measured at these additional kVp's).

12. Repeat the procedure at other breast (phantom) thicknesses and appropriate kVp and density settings, if desired.

13. Make sure the exposed film in the cassette is replaced before the cassette is returned to use.

The above procedure is repeated for each target/filter combination available on the system. Data is recorded on a spreadsheet, an example of which is shown in Appendix D.

Data Interpretation and Analysis (these are automatically performed on the provided spreadsheet)

1. For each breast thickness examined, average the four entrance skin exposure measurements.

2. Using the tables provided below, look up the dose conversion factor for the HVL, kVp and Target/Filter combination, used at each breast thickness. The dose conversion factor is equivalent to the mean glandular dose (mrad) per Roentgen entrance skin exposure. Tables 9, 10 and 11 are taken from the ACR Medical Physicists Manual(32), and are appropriate for Mo/Mo, Rh/Mo, and Rh/Rh target/filter combination, respectively. For the appropriate combination find the HVL of the system in the left-hand column. In the right-hand column

appropriate for the kVp setting, find the exposure to average glandular dose conversion factor for a 4.2 cm compressed breast thickness.

3. Multiply the dose conversion factor by the average entrance skin exposure computed above. The product obtained represents the mean dose received by the glandular tissue for that specific energy, breast composition and compression thickness and is an approximation of the actual patient dose.

TABLE 9. Glandular Dose (in mrad) for 1 Roentgen Entrance Exposure 4.2 cm Breast Thickness - 50% Adipose/50% Glandular Breast Tissue(33)

	Mo/Mo Target Filter X-Ray Tube Voltage (kVp)											W/Al Target/Filter Combination
HVL	23	24	25	26	27	28	29	30	31	32	33	
0.23	116											
0.24	121	124										
0.25	126	129	131									
0.26	130	133	135	138								
0.27	135	138	140	142	143							
0.28	140	142	144	146	147	149						
0.29	144	146	148	150	151	153	154					
0.3	149	151	153	155	156	157	158	159				170
0.31	154	156	157	159	160	161	162	163	164			175
0.32	158	160	162	163	164	166	167	168	168	170	171	180
0.33	163	165	166	168	169	170	171	173	173	174	175	185
0.34	168	170	171	172	173	174	175	176	177	178	179	190
0.35		174	175	176	177	178	179	180	181	182	183	194
0.36			179	181	182	183	184	185	185	186	187	199
0.37				185	186	187	188	189	190	191	191	204
0.38					190	191	192	193	194	195	195	208
0.39						196	197	198	198	199	200	213
0.4							201	202	203	204	204	217
0.41								206	207	208	208	221
0.42									211	212	212	225
0.43										215	216	230
0.44											220	234
0.45												238

TABLE 10. Glandular Dose (in mrad) for 1 Roentgen Entrance Exposure to a 4.2-cm Breast Thickness-50% Adipose/50% Glandular Breast Tissue Using an Mo/Rh Target/Filter Combination(34)

	X-Ray Tube Voltage (kVp)										
HVL	25	26	27	28	29	30	31	32	33	34	35
0.28	149	151	154								
0.29	154	156	158	159							
0.3	158	160	162	162	163						
0.31	163	164	166	166	167	167					
0.32	167	169	171	171	171	172	172				
0.33	171	173	175	176	176	176	176	177			
0.34	176	178	179	179	180	180	180	181	181		
0.35	180	181	183	183	184	185	185	186	187		
0.36	185	186	187	187	188	188	189	190	191	191	
0.37	189	190	191	191	192	193	193	194	195	195	
0.38	193	194	196	196	197	197	197	198	199	199	200
0.39	198	199	200	200	201	201	202	202	203	203	204
0.4	202	203	204	204	205	205	206	207	208	208	208
0.41	206	207	208	208	209	209	210	211	212	212	212
0.42	211	211	212	212	213	213	214	215	216	216	217
0.43	215	216	217	217	218	218	219	219	220	220	221
0.44	220	220	221	221	222	222	223	223	224	224	225
0.45	224	224	225	225	226	226	227	227	228	228	229
0.46		228	229	229	230	231	231	232	233	233	234
0.47			233	233	234	235	235	236	237	237	238
0.48			238	238	239	240	240	241	241	242	242
0.49				242	243	243	244	244	245	245	246
0.5					247	247	248	248	249	250	251
0.51						251	252	253	254	254	255
0.52							257	257	258	258	259
0.53							261	261	262	263	264
0.54								265	266	267	268
0.55								269	270	271	272
0.56									275	276	276
0.57									279	280	281
0.58										284	285
0.59										288	289
0.6											293

TABLE 11. Glandular Dose (in mrad) for 1 Roentgen Entrance Exposure to a 4.2-cm Breast Thickness-50% Adipose/50% Glandular Breast Tissue Using an Rh/Rh Target/Filter Combination(35)

	X-Ray Tube Voltage (kVp)										
HVL	25	26	27	28	29	30	31	32	33	34	35
0.28	150	155	159								
0.29	155	160	164	168							
0.3	160	164	168	172	176						
0.31	165	168	172	174	180	182					
0.32	169	173	177	181	184	186	188				
0.33	174	178	181	185	188	190	192				
0.34	179	183	186	190	193	195	196	199			
0.35	184	187	190	194	197	199	201	203			
0.36	189	192	195	198	201	204	205	207	209		
0.37	193	196	199	202	205	207	209	211	213		
0.38	199	201	204	207	209	211	213	215	217	219	221
0.39	203	206	208	211	214	216	217	219	221	223	224
0.4	208	211	213	216	218	220	221	223	224	226	228
0.41	213	215	217	220	222	224	225	227	228	230	232
0.42	218	220	222	224	226	228	229	231	232	234	236
0.43	222	224	226	228	230	232	233	235	236	238	240
0.44	227	229	231	233	235	237	238	239	240	242	243
0.45	232	234	235	237	239	241	242	243	244	246	247
0.46			239	241	243	245	246	247	248	250	251
0.47					247	249	250	251	252	254	255
0.48					251	253	254	255	256	258	259
0.49						257	258	259	260	261	262
0.5						261	262	263	264	265	266
0.51							266	267	268	269	270
0.52							270	271	272	273	274
0.53							275	276	276	277	278
0.54								279	280	280	281
0.55								283	284	284	285
0.56									288	288	289
0.57										292	293
0.58										296	297
0.59											300
0.6											304

4. Efforts by Wu and Sobol(36) have lead to a parameterization of the above tables to result in a series of analytical expressions that match the tabulated results with known uncertainties. This parameterization was performed for each of the filter/target combinations, as well as for three different breast compositions: 100% adipose, 50% adipose and 50% glandular, and 100% glandular. The analytical expressions provide the normalized glandular dose for any breast composition within stated ranges of the tabulated input parameters: kVp, HVL and breast thickness. These expressions have been coded as macros into an Excel spreadsheet, allowing them to be called as functions. The three functions have the following format:

(a) Molybdenum Target and Molydenum Filter: MoMo(kVp, HVL, d, G)

(b) Molybdenum Target and Rhodium Filter: MoRh(kVp, HVL, d, G)

(c) Rhodium Target and Rhodium Filter: RhRh(kVp, HVL, d, G)

where kVp is the operating potential, HVL is the half-value layer in mm Al at that potential, d is the allowable range of breast thicknesses in cm, and G is the fraction of glandular tissue in the breast: 0 = no glandular tissue, 1 = all glandular tissue.

The spreadsheet included with this report incorporates these functions and automatically calculates the mean glandular dose. Appendix D provides a sample of the developed worksheet as well as guidance on its use.

Performance Criteria and Typical Doses

The American College of Physicists in Medicine (AAPM) has reported the dosimetry results from National Evaluation of X-Ray Trends (NEXT) study using the ACR phantom, a 4.5 cm thick breast composed of 50% adipose tissue and 50% glandular tissue. The "national average" mean glandular dose for this phantom is 1.42 mGy (142 mrad) per view for screen-film mammography with grid(37). The AAPM has recommended that a mean glandular dose which exceeds 1.8 mGy (180 mrad) per view with grid and 0.9 mGy (90 mrad) per view without grid, for 4.5 cm thick breast, should be investigated. A 4.2 cm PMMA phantom is equivalent to a 4.2 cm 50/50 breast(38).

The American College of Radiology recommends that the average glandular dose assessed using the ACR phantom (e.g. RMI model 156, equivalent to 3.84 cm PMMA) should not exceed 3 mGy (300 mrad) per view for screen-film image receptors. It is recommended that the average glandular dose should be less than 100 mrad per view for non-grid screen-film image receptors, and less than 300 mrads per view for grid screen-film imaging modes. If the values exceed these levels, action should be taken to evaluate and eliminate the cause of the excess dose.

DOSE REDUCTION AND ORGAN DOSE ASSESSMENT

Recommendations to Minimize Patient Dose

The International Commission of Radiological Protection and the National Council on Radiation Protection have put fourth a series of recommendations for protecting the patient in diagnostic radiology from the risks of radiation exposure(39,40). Specifically, the ICRP supports the basic tenants that unnecessary exposure should be avoided; necessary exposures should be justifiable in terms of benefits that would not have otherwise been received, and that doses actually administered should be limited to the minimum amount consistent with the medical benefit to the individual patient. The following NCRP-recommendations summarize the basic policies and procedures that should be followed in radiology to minimize patient (and staff) dose.

1. The useful beam shall be limited to the smallest area practical for the radiological examination.

2. The tube potential, filtration and SSD used for diagnostic examination should be as large as possible.

3. Protection of the embryo or fetus during radiological examination or treatment of women known to be pregnant should be given special consideration.

4. Elective abdominal/pelvic examination of a woman of childbearing age should be performed during the first 14 days following the onset of menses to minimize the possibility of irradiation of the embryo(41).

5. Sensitive body organs (e.g. lens of eye gonads) should be shielded whenever they are likely to be exposed to useful beam provided such shielding does not interfere with the diagnostic information. (Minimum lead thickness of 0.5 mm for gonads and 2 mm for eyes)

6. Fluoroscopy is not used as a substitute for radiography.

7. X-Ray films, intensifying screens, and other recording devices are periodically reviewed for maximum sensitivity.

8. The x-ray beam is always aligned with patient and the image receptor.

9. No person should routinely hold patients during diagnostic examinations.

a. When a patient must be held in position, mechanical supports should be used.

b. Pregnant woman or persons under 18 years should not hold patients.

c. If a patient must be held by someone, the individual shall be protected with appropriate shielding devices such as gloves and aprons. No part of the holders torso shall be struck by the useful beam.

10. Only individuals whose presence is necessary shall be in the x-ray room during exposures. These personnel shall wear protective clothing.

11. The operator shall stand behind a barrier, if provided, and shall observe the patient during exposures.

Quality Control

Patient dose is also minimized through the proper maintenance, calibration and quality control of both the radiographic and film processing systems. The JCAHO requires a quality control program in radiology for this very reason, as well as to insure optimal image quality. Guidance on developing and conducting a radiology quality control program is beyond the scope of this document, but can be found in detail in the following references. Note that a well developed QA/QC program will considerably augment the annual calibration of x-ray systems conducted by MERC.

1. Gray, Joel E., "Quality Control in Diagnostic Radiology", University Park Press, 1983

2. American Association of Physicists in Medicine, Specification, Acceptance Testing and Quality Control of Diagnostic X-Ray Imaging Equipment. AAPM Monograph 20, 1991 AAPM Annual Summer School Proceedings held at University of California, Santa Cruz, 1994.

3. KODAK, Management of Radiographic Environments (MORE 2) Course Manuals, 1985

4. KODAK, RP-XOMATIC Processor Course Manual

5. Radiation Measurements Incorporated (RMI), Quality Assurance Handbook, RMI, Middleton WI.

6. National Council on Radiation Protection and Measurements, Quality Assurance for Diagnostic Imaging, NCRP Report 99, NCRP, Bethesda MD, 1988.

Actual Entrance-Skin-Exposure and Organ Dose Assessment

It was earlier presented that determining the dose to an actual organ or to the conceptus from diagnostic radiographic procedures is complex. Computer models have been generated which allow an estimate of organ dose from the measured ESE data, exposure technique and projection measurements for a given radiograph, but there can be considerable uncertainty in this estimate(42). Even less accurate are tabulated values of tissue dose for a given ESE and

technique(43). Further, such methods do not readily address the exposure conditions common to CT and interventional fluoroscopy.

The most accurate method to assess patient entrance skin exposure is to use personnel monitoring devices for the patient. Similar to the dosimeters used to monitor occupational exposures, the thermoluminescent dosimeters (TLDs) employed for patient dose assessment are small chips of lithium-fluoride or lithium-borate which can be affixed directly to the patient. Calibration of the TLDs prior to exposure to the energy of the x-ray system allows an accurate determination of the shallow dose received by the skin. As discussed previously, this method is preferred for interventional radiographic procedures where very high entrance skin exposures can result. Single or sets of chips for this application can be acquired from our organization or from a number of vendors who specialize in TLD services. 3

When there is justification for a precise determination of organ dose or the dose to a conceptus from a given radiographic procedure, the best alternative is to use an anthropormorphic, tissue equivalent phantom which is capable of being loaded with TLDs at organ locations of interest. An example is the RANDO phantom 4, which consists of a human torso and head divided in 2.5 cm slices. Hole grid patterns at 1.5 and 3 cm intervals are drilled into each slice to allow the insertion of TLDs. Once a suitable phantom is loaded with dosimeters, it can be exposed to the radiographic study of interest. All efforts are made to replicate as closely as possible the exposures received by the actual patient. Evaluation of the exposed dosimeters allows a fairly accurate assessment of the actual organ or conceptus dose in the patient. Because of the specialized equipment and procedures required for this assessment, it is normally conducted by a qualified medical or health physicist. Contact either our organization, or the radiation safety department of Wilford Hall Medical Center (DSN 554-7957), if these services are desired.

SUMMARY AND CONCLUSIONS

This report has attempted to provide a comprehensive description of the methods used to evaluate dose in conventional radiology. This evaluation is necessary not only to meet JCAHO requirements, but also to address the ICRP recommendation that "doses actually administered should be limited to the minimum amount consistent with the medical benefit to the individual patient". To assist in the assessment process, specific recommendations on equipment and methods have been described for conventional radiography, fluoroscopy, computed tomography and mammography. A series of spreadsheets have been included with this report to simplify data interpretation and allow easy storage of dose records.

Determination of patient dose should be made an integral part of normal radiology or dental radiology quality control programs. The references included in chapter 5 provide detailed descriptions of all necessary aspects of these programs, including repeat analysis, film processor quality control, and x-ray system quality control. Annual or bi-annual determination of patient dose provides a valuable (and required) component of your QA/QC program to insure optimal diagnostic quality of images while minimizing patient risk.

If additional information is necessary, please feel free to contact AL/OEBZ at DSN 240-3486.

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[3] An example is K&S Associates, Inc, 1926 Elm Tree Dr, Nashville TN 37210. Http :www kslab.com/ks

[4] Available from The Phantom Laboratory, 1(800)525-1190, PO Box 511, Salem NY, 12865-0511

REFERENCES

1 American Association of Physicists in Medicine. An analysis of the new JCAHO standards for diagnostic radiology and nuclear medicine (brochure). New York, NY, 1989

2. American Association of Physicists in Medicine. Standardized methods for measuring diagnostic x-ray exposures, AAPM Report 31. New York NY, 1990.

3. Wagner LK, Eifel PJ, and Geise RA. Potential biological effects following high x-ray dose interventional procedures. Journal of Vascular nd Interventional Radiology 5:71-84, 1994.

4. Food and Drug Administration, Avoidance of serious x-ray-induced skin injuries to patients during fluoroscopically-guided procedures. FDA Notice. 9 September, 1994.

5. Peterson L.E., and Rosenstein M. Computer program for tissue doses in diagnostic radiology, Food and Drug Administration, Center for Devices and Radiological Health, Rockville, MD, April 1989.

6 Conference of Radiation Control Program Directors. Nationwide evaluation of x-ray trends (NEXT), tabulaion and graphical summary of survey 1984 through 1987. Franfort, Ky, 1989.

7. Kerlakes JG and Rosenstein M, Handbook of radiation doses in nuclear medicine and diagnsotic x-ray. Boca Raton Fl, CRC, 212-213, 1980.

8. The President. Radiation Protection Guidance to Federal Agencies for Diagnostic X-rays. Federal Register, Vol 43, No 22. 1 Feb 1978

9 Conference of Radiation Control Program Directors, Inc 1991

10 Curry TS, Dowdey JE, and Murry RC. Christensen's Physics of Diagnostic Radiology, Fourth Ed. Lea & Febiger, Philadephia PA, 1990; 35.

11 Curry TS, Dowdey JE, and Murry RC. Christensen's Physics of Diagnostic Radiology, Fourth Ed. Lea & Febiger, Philadephia PA, 1990; 240

12. Dixon, RL. Patient Dose Determination and Evalaution in Diagnostic Radiology. in "Specification, acceptance testing and quality control of diagnostic x-ray imaging equipment". AAPM Monograph no. 20, American Association of Physicists in Medicine, American Institute of Physics, Woodbury NY, 1994;1045.

13 Conway BJ, Duff JE, Fewell TR, Jenning RJ. A patient equivalent phantom for estimating patient exposures from automatic exposure controlled x-ray examinations of the abdomen and lumbo-sacral spine. Med Phys 1990; 17 448-453

14 Scientific Exhibit 060PH at the 81st Scientific Asssembly and Annual Meeting of the Radiological Society of North America, November 26 - December 1, 1995. Radiology Vol. 197(P) Supplement, P449.

15 Dixon, RL. Patient Dose Determination and Evalaution in Diagnostic Radiology. in "Specification, acceptance testing and quality control of diagnostic x-ray imaging equipment.". AAPM Monograph no. 20, American Association of Physicists in Medicine, American Institute of Physics, Woodbury NY, 1994;1049.

16 National Council on Radiation Protection and Measurements. Quality Assurance for Diagnostic Imaging. NCRP Report 99, NCRP, Bethesda MD, 1995;87.

17 National Council on Radiation Protection and Measurements. Quality Assurance for Diagnostic Imaging. NCRP Report 99, NCRP, Bethesda MD, 1995;89

18 Intersociety Commission for Heart Disease. Optimal resources for examination of the heart and lungs: Cardiac catheterization and radiographic facilities. Examination of the Chest and Cardiovascular System Study Group. Circulation, 68, 1983,893A-930A.

19 High M. Digital Fluoro Acceptance Testing. in "Specification, acceptance testing and quality control of diagnostic x-ray imaging equipment". AAPM Monograph no. 20, American Association of Physicists in Medicine, American Institute of Physics, Woodbury NY, 1994,721

20 Federal Register, vol 59, no 96 Washington DC: Government Printing Office, 1994;26402-26405

21. Gray JE and Swee RG. The elimination of grids during intensified fluoroscopy and photofluorospot imaging. Radiology 144, 1982;426-429.

22. National Council on Radiation Protection and Measurements. Quality Assurance for Diagnostic Imaging. NCRP Report 99, NCRP, Bethesda MD, 1995;86.

23. Burlington B.D., FDA Public Health Advisory: Avoidance of Serious X-Ray-Induced Skin Injuries to Patients During Fluoroscopically-Guided Procedures, Food and Drug Administration, 30 Sep 1994, (http://www.fda.gov/cdrh/fluor.html).

24. Shope TB, Gagne RM, and Johnson GC. A method for describing the doses delivered by transmission x-ray computed tomography. Med. Phys. 1981(8);488.

25. Code of Federal Regulation, Title 21, Part 1020, Section 33. Computed Tomography (CT) equipment, Food and Drug Administration, Center for Devices and Radiological Health, 1986.

26. McCrohan ZJL, Patterson JF, Gagne RM, et al. Average radiation doses a standard head examination for 250 CT scanners. Radiology 163, 1987;263.

27. Mini RL, Vock P, Mury R, Schneeberger PP. Radiation exposure of patients who undergoe CT of the trunk. Radiology 19, (1995)557-562.

28. ICRU, Radiation Dosimetry: X-rays Generated at Potentials of 5 to 150 kV. ICRU Report 17, International Commission on Radiation Units and Measurements, Washington DC. 1970;28.

29. Johns HE, Cunningham JR, The Physics of Radiogy, Charles C Thomas, Springfield, Il. 1983;737.

30. National Council on Radiation Protection and Measurements. Quality Assurance for Diagnostic Imaging. NCRP Report 99, NCRP, Bethesda MD, 1995;122.

31. American College of Radiology, Mammography Quality Control Manual, Medical Physicists Section, Committee on Quality Assurance in Mammography, 1994.

32. American College of Radiology, Mammography Quality Control Manual, Medical Physicists Section, Committee on Quality Assurance in Mammography, 1994.

33. Adapted from: Wu X. Breast dosimetry in screen-film mammography. In: Barnes GT, Frey GD (eds), Screen film mammography: imaging considerations and medical physics responsibilities. Madison, WI: Medical Physics Publishing; 1991: 159-175. W/Al conversion factors are derived from fits to data from Stanton L et al. Dosage evaluation in mammography. Radiology 150:577-584; 1984.

34. Adapted from: Wu X, Gingold EL, Barnes GT, Tuker DM. Normalized average glandular dose in Mo/Rh and Rh/Rh target/filter mammography. Radiology 1994: in press.

35. Adapted from: Wu X, Gingold EL, Barnes GT, Tuker DM. Normalized average glandular dose in Mo/Rh and Rh/Rh target/filter mammography. Radiology 1994: in press.

36. Sobel WT and Wu X, Parameterization of mammography normalized average glandular dose tables. Medical Physics. 24(4), 1997; 547.

37. American Association of Physicists in Medicine, Standardized methods for measuring diagnostic x-ray exposures. AAPM Report 31. New York, N, 1990.

38 American Association of Physicists in Medicine. Equipment requirements and quality control for mammography. AAPM Report 29. New York NY, 1990.

39. International Commission on Radiological Protection, Protection of the Patient in Diagnostic Radiology, ICRP Publication 34, Pergamon Press, New York NY, 1982

40. National Council on Radiation Protection and Measurements, Medical X-Ray and Gamma-Ray Protection for Energies up to 50 MeV. NCRP Report 102, NCRP, Bethesda MD, 1994.

41. National Council on Radiation Protection and Measurements, Medical Radiation Exposure of Pregnant and Potentially Pregnant Women. NCRP Report 54, NCRP, Bethesda MD, 1979.

42. Peterson LE and Rosenstein M, Computer Program for Tissue Doses in Diagnostic Radiology. Food and Drug Administration, Center for Devices and Radiological Health, Rockville MD, 1989.

43. Keriakes JG and Rosenstein M, Handbook of radiation doses in nuclear medicine and diagnostic x-ray. Boca Raton Fl, CRC; 1980

APPENDIX A

APPENDIX A: INSTRUCTIONS FOR ASSESSING RADIOGRAPHIC ENTRANCE SKIN EXPOSURES USING THE EXCEL ESE SPREADSHEET

1. The spreadsheets are in Excel 7.0 format. Different pages can be produced within a single file for each unit within a given clinic or facility.

2. Each spreadsheet is 5 pages long, with all useful data in columns A through I, lines 1 through 240. The following summarizes the information contained on each page.

a. Section A (Page 1). contains some basic data concerning the unit and several reference measurements by which the ESE measurements presented on page 2 are determined.

b. Section B (Page 1). contains the raw radiation output measurements taken during either by the department using procedures described in Chapter 2, or pulled directly from the last MERC calibration of the unit. In summary, a series of precise exposure measurements are taken at 10 mAs through the range of kVps which the system is clinically used. The measured exposure at each kVp is divided by the mAs, to give exposure in units of mR/mAs. The 10 data points are fit to a quadratic equation of the form:

$$\frac{mR}{mAs} = \alpha + \beta kVp + \gamma kVp^2$$

The "Fit" column in this section presents the calculated mR/mAs using this quadratic equation and the "%Diff" is the percent difference between the measured and calculated value. As can be seen, the data is typically within a few percent of the calculated result. Examination of the regression analysis and graphed results of the fit are found to the left of column I.

c. Section C (Page 1): contains the entrance skin exposure measurements for several important techniques and a comparison between values measured directly and those calculated from the results in section B. Several important findings are derived from this section. First, the ESE results should be less than the "Guide" values suggested by the Food and Drug Administration. These guidance values are extremely liberal, and any modern calibrated system using rare earth screens should easily meet these limits. Second, the measured and calculated ESE values are compared and the percent difference is calculated. Ideally, the difference between the measured and calculated values is within 5%. The "measured" and "calculated" ESE values are determined in the following manner:

1. The ESE measured values were assessed by first measuring the free air exposure at the source to chamber distance (SCD) listed in section B. at the appropriate techniques for the system and screen/film combination. For example, a PA Chest for an average size adult has a technique of 110 kVp and 4 mAs. The free air exposure measured with this technique at an SCD of 36.5 inches was 34.9 mR. The ESE is then calculated using an inverse square law from the following relationship:

$$ESE(mR) = \left[\frac{SCD}{SID - (ITTD + PT)}\right]^2 Exposure(mR) \qquad (1)$$

where SCD = Source to Chamber Distance (36.5")
SFD = Source to Film Distance (72")
TTFD = Table Top to Film Distance (2.5")
PT = Patient Thickness (9")

The SFD and PT come from data for the Chest technique in Section C. and the TTFD comes from Section A. 5. Putting this data in the above equation results in a ESE of 13 mR.

2. The calculated ESE is determined using the same inverse square relationship, but also calculates the free air exposure at 36.5 inches using the kVp and mAs for the technique and the quadratic equation determined in section B. The complete expression for the calculated ESE is then:

$$ESE(mR) = \left[\frac{SCD}{SID - (ITTD + PT)}\right]^2 (\alpha + \beta kVp + \gamma kVp^2) mAs \qquad (2)$$

b. Section D, (Page 2): The table on this page presents the calculated ESE for the full mAs and kVp range of the system. The ESE is calculated in each cell using equation (2), with data coming from the following cells in the spreadsheet:

mAs: Column A of the row the cell is in.
kVp: Row 56 of the column the cell is in.
SID: Section A, Part 4.
TTFD: Section A, Part 5.
PT: Section A, Part 6.
α,β,γ: From Section B
SCD: From Section B

Data elements in part A, 4 - 6 can be manipulated by you to determine the ESE at any specific kVp, mAs, SFD, TTFD, or PT desired. For example, if the patient is a different thickness, change the value listed in Section A, part 6. If a specific technique is desired, find the closest mAs in Column A and closest kVp in row 56 and change these values to those used. The cell where this row and column intersect presents the desired ESE.

c. Section E. (Pages 3. through 5). These pages provide a template for the producing readily available tables of ESE data for all the procedures commonly performed on a given system. The ESE calculated is based on equation 2, and the data provided for a specific procedure.

1. The table comes pre-loaded (red data values) with the procedures and techniques programmed into a GE Advantix radiographic system, and common patient thickness for the average adult. Change this data to that actually used for your system for a given procedure for the patient size of interest. Multiple pages can be set up to serve as both a technique chart and ESE guide for various patient sizes. When you complete this section, be sure to "SAVE" the file so your entered data is not lost.

2. The spreadsheet is already set up to print the five pages making up the form.

3. Some more caveats: The data calculated in these pages should be accurate to within $\pm$ 5% of the actual ESE for the patient. The data is valid for one year from the date of measurement unless any major part of the x-ray system is replaced or if medical maintenance re-calibrates the system.

3. Sample Of Excel ESE Spreadsheet Output

JCAHO FREE AIR ENTRANCE SKIN EXPOSURE

A. SYSTEM PARAMETERS COMMONLY USED:

		Minimum	Maximum
1.	System Designation:	Tomographic Unit. Room 1, Lakenheath	
2.	Range of kVps:	50	130
3.	Range of mAs:	1	500
4.	Source to Image Distance:	40 in	
5.	Table Top to Film Distance:	4 in	
6.	Patient (Body Part Thickness):	23 cm	

B. RADIATION OUTPUT MEASUREMEN:

Technique:	10 mAs
Source to Chamber Distance:	36.5 in
Inverse Square Correction Factor:	1.83

	kVp	Exposure mR	mR/mAs	Fit	%Diff
1.	140	182.6	18.26	18.24	-0.14
2.	130	161.3	16.13	16.14	0.08
3.	120	141.2	14.12	14.12	0.02
4.	110	121.5	12.15	12.18	0.22
5.	100	101.6	10.16	10.30	1.41
6.	90	87	8.7	8.50	-2.26
7.	80	68.6	6.86	6.78	-1.22
8.	70	50.3	5.03	5.12	1.85
9.	60	34.6	3.46	3.54	2.38
10.	50	20.9	2.09	2.04	-2.63

Fit: mR/mAs= -4.4035 + 0.11048 kVp + 0.00037 kVp^2

C. MEASURED ENTRANCE-SKIN-EXPOSURE DATA:

	Films per Wk	kVp	mAs	SID (in)	TTFD (in)	Patient (in)
1. Chest (PA)	65	120	2.5	72	2.75	9
2. Skull (Lat)	1	70	10	44	4	6
3. Abdomen AP	6	70	64	44	4	9
4. Cervical Spine AP	6	70	16	44	4	5
5. Thoracic Spine AP	1	70	32	44	4	9
6. L-S Spine (AP)	8	70	64	44	4	9
7. Retrograde Pyel.	1	70	64	44	4	9

	Exposure (mR) Measured	ESE	FRP Guide	Calculated ESE	Fit Error %
1. Chest (PA)	34.9	12.81	30	12.96	-1.17
2. Skull (Lat)	50.2	57.85	300	59.04	-2.05
3. Abdomen AP	316	438.08	750	454.52	-3.75
4. Cervical Spine AP	80.6	87.66	250	89.14	-1.69
5. Thoracic Spine AP	160	221.81	900	227.26	-2.46
6. L-S Spine (AP)	318	440.85	1000	454.52	-3.10
7. Retrograde Pyel.	318	440.85	900	454.52	-3.10

D. CALCULATED FREE AIR ENTRANCE-SKIN-EXPOSURE

Source to Chamber Distance: 36.5 in
Source to Image Distance: 40 in
Table Top to Film Distance: 4 in
Patient Thickness: 23 cm

mAs	kVp 50	70	80	90	100	110	120	130
1	3.7	9.4	12.4	15.6	18.9	22.3	25.9	29.6
2	7.5	18.8	24.9	31.2	37.8	44.7	51.8	59.2
4	14.9	37.6	49.7	62.4	75.6	89.4	103.7	118.5
6	22.4	56.4	74.6	93.6	113.4	134.1	155.5	177.7
8	29.9	75.2	99.5	124.8	151.3	178.7	207.3	237.0
10	37.3	94.0	124.3	156.0	189.1	223.4	259.2	296.2
12	44.8	112.8	149.2	187.2	226.9	268.1	311.0	355.5
14	52.3	131.6	174.1	218.4	264.7	312.8	362.8	414.7
16	59.7	150.4	199.0	249.7	302.5	357.5	414.6	473.9
18	67.2	169.2	223.8	280.9	340.3	402.2	466.5	533.2
20	74.7	188.0	248.7	312.1	378.1	446.9	518.3	592.4
22	82.2	206.8	273.6	343.3	415.9	491.6	570.1	651.7
24	89.6	225.6	298.4	374.5	453.8	536.2	622.0	710.9
26	97.1	244.4	323.3	405.7	491.6	580.9	673.8	770.1
28	104.6	263.2	348.2	436.9	529.4	625.6	725.6	829.4
30	112.0	282.0	373.0	468.1	567.2	670.3	777.5	888.6
32	119.5	300.8	397.9	499.3	605.0	715.0	829.3	947.9
34	127.0	319.6	422.8	530.5	642.8	759.7	881.1	1007.1
36	134.4	338.4	447.6	561.7	680.6	804.4	932.9	1066.4
38	141.9	357.2	472.5	592.9	718.4	849.1	984.8	1125.6
40	149.4	376.0	497.4	624.1	756.3	893.7	1036.6	1184.8
42	156.8	394.8	522.3	655.3	794.1	938.4	1088.4	1244.1
44	164.3	413.6	547.1	686.5	831.9	983.1	1140.3	1303.3
46	171.8	432.4	572.0	717.8	869.7	1027.8	1192.1	1362.6
50	186.7	470.0	621.7	780.2	945.3	1117.2	1295.8	1481.1
52	194.2	488.8	646.6	811.4	983.1	1161.9	1347.6	1540.3
54	201.7	507.6	671.5	842.6	1020.9	1206.6	1399.4	1599.5
56	209.1	526.4	696.3	873.8	1058.8	1251.2	1451.3	1658.8
58	216.6	545.2	721.2	905.0	1096.6	1295.9	1503.1	1718.0
60	224.1	564.0	746.1	936.2	1134.4	1340.6	1554.9	1777.3
65	242.7	611.0	808.3	1014.2	1228.9	1452.3	1684.5	1925.4
70	261.4	658.0	870.4	1092.2	1323.4	1564.1	1814.1	2073.5
75	280.1	705.0	932.6	1170.3	1418.0	1675.8	1943.6	2221.6
80	298.7	752.0	994.8	1248.3	1512.5	1787.5	2073.2	2369.7
90	336.1	846.0	1119.1	1404.3	1701.6	2010.9	2332.4	2665.9
100	373.4	940.0	1243.5	1560.3	1890.6	2234.4	2591.5	2962.1
110	410.8	1034.0	1367.8	1716.4	2079.7	2457.8	2850.7	3258.3
120	448.1	1128.0	1492.2	1872.4	2268.8	2681.2	3109.8	3554.5
130	485.5	1222.0	1616.5	2028.4	2457.8	2904.7	3369.0	3850.7
140	522.8	1316.0	1740.9	2184.5	2646.9	3128.1	3628.1	4146.9
150	560.2	1410.0	1865.2	2340.5	2836.0	3351.5	3887.3	4443.2
200	746.9	1880.1	2486.9	3120.7	3781.3	4468.7	5183.0	5924.2
250	933.6	2350.1	3108.7	3900.9	4726.6	5585.9	6478.8	7405.3
300	1120.3	2820.1	3730.4	4681.0	5671.9	6703.1	7774.6	8886.3

E. Entrance-Skin-Exposure Assessed by Procedure:

General Site	Specific Site	View	SID (in)	TTID (in)	Thick (cm)	kVp	mAs	Exposure (mR)
Thoracic	Chest	PA/AP	72	2.75	23	110	4	17.9
Thoracic	Chest	Lat.	72	2.75	30	120	8	45.6
Thoracic	Chest	RAO-Obl	72	2.75	30	115	4	21.2
Thoracic	Chest	LAO-Obl	72	2.75	30	115	4	21.2
Thoracic	Chest	Decubitus	72	2.75	23	110	5	22.4
Thoracic	Chest	Lordotic	72	2.75	23	110	4	17.9
Thoracic	Ribs/ab diap	AP	44	4	20	70	20	132.3
Thoracic	Ribs/ab diap	Obl.	44	4	25	70	25	187.6
Thoracic	Ribs/bel diap	AP	40	0	20	70	32	211.6
Thoracic	Sternum	RAO	44	4	30	65	50	362.4
Thoracic	Sternum	Lat.	40	0	30	75	40	398.4
Abdomen	Abdomen	KUB/flat	40	0	23	75	32	264.5
Abdomen	Abdomen	Upright	44	4	23	70	40	285.1
Abdomen	Abdomen	Decubitus	44	4	23	70	32	228.1
Abdomen	Abdomen	Lat.	44	4	30	75	50	498.0
Head	Skull@Sella	PA/AP	44	4	20	66	20	115.7
Head	Skull	Caldwell	44	4	20	63	20	103.5
Head	Skull	Towne	44	4	20	68	25	154.9
Head	Skull@Sella	Lat.	44	4	15	66	32	164.4
Head	Skull	Basalar	44	4	20	70	32	211.6
Head	Sinuses&Nasal	Waters	44	4	20	68	20	123.9
Head	Sinuses	Lateral	44	4	20	64	8	43.0
Head	Sinuses	SMV	44	4	20	80	32	279.9
Head	Nasal	Lat	44	0	15	58	3.2	9.5
Head	Facial Bones	Waters	44	4	20	68	20	123.9
Head	Facial Bones	Lat	44	4	20	64	8	43.0
Head	Facial Bones	Caldwell	44	4	20	68	20	123.9
Head	Facial Bones	Zygomatic Arch	50	0	20	65	10	32.5
Head	Mastoids	Stenvers/Arceli n	44	4	15	70	16	93.9
Head	Mastoids	Schullers/Laws	44	4	15	70	12.5	73.4
Head	Mastoids	Towne	44	4	15	68	32	176.1
Head	Orbits	Waters	44	4	20	65	20	111.6
Head	Orbits	Lat	44	4	15	64	8	38.2
Head	Orbits	Reese (optic)	44	4	15	68	16	88.0
Head	Mandible	PA	44	4	16	68	16	90.1
Head	Mandible	Towne	44	4	16	68	32	180.2
Head	Mandible	Lat/Obl	44	4	16	66	12.5	65.7
Head	Mandible	TMJ-lat	44	4	16	66	16	84.1

E. Entrance-Skin-Exposure Assessed by Procedure (Con't):

General Site	Specific Site	View	SID (in)	TTID (in)	Thick (cm)	kVp	mAs	Exposure (mR)
Spine	Cervical	AP	44	4	23	70	8	57.0
Spine	Cervical	Op-Mth Odont	44	4	23	70	8	57.0
Spine	Cervical	Lat	72	2.5	30	80	16	43.4
Spine	Cervical	Obl.	72	2.5	27	80	16	41.7
Spine	Cervical	Flex/Ext	72	2.5	23	80	16	39.5
Spine	Cervical	Soft Tissue	72	2.5	23	80	16	39.5
Spine	Cervical	Odontoid Blur	44	4	23	70	10	71.3
Spine	Thoracic	AP	44	4	23	76	32	271.9
Spine	Thoracic	Lat	44	4	30	76	80	819.0
Spine	Thoracic	Lat/Breath	44	4	23	76	50	424.8
Spine	Thoracic	Swimmers	44	4	23	76	64	543.7
Spine	Lumbar	AP/Obl	44	4	27	76	40	377.2
Spine	Lumber	Lat	44	4	30	100	100	1727.4
Spine	Lumbar	Spot-L5	44	4	23	86	100	1085.7
Spine	Sacrum	AP/Angled	44	4	23	76	40	339.8
Spine	Coccyx/Sacrum	Lateral	44	4	30	100	80	1381.9
Spine	Coccyx	AP/Angled	44	4	23	76	40	339.8
Spine	Scroiliac Joints	AP/Obl	44	4	23	76	40	339.8
GB/UGI	Gallbladder	PA/Oblique	44	4	23	69	32	220.9
GB/UGI	Esophagus	AP/PA fluoro	44	4	23	120	4	78.6
GB/UGI	Esophagus	Obl.	44	4	27	120	4	87.2
GB/UGI	Esophagus	Lat	44	4	30	120	8	189.4
GB/UGI	Upper GI	AP/PA fluoro	44	4	23	120	8	157.2
GB/UGI	Upper GI	Obl.	44	4	27	120	12.5	272.7
GB/UGI	Upper GI	Lat	44	4	30	120	16	378.9
GB/UGI	Small Bowel	(Fluoro)	44	4	23	120	10	196.5
GB/UGI	Gastrografin-UGI	AP/PA fluoro	44	4	23	90	6.4	75.7
GB/UGI	Gastrografin-UGI	Obl.	44	4	27	90	6.4	84.1
GB/UGI	Gastrografin-UGI	Lat	44	4	30	90	6.4	91.2
GI - Colon	Colon	Scout	44	4	23	80	12.5	117.8
GI - Colon	Colon - Air C.	AP/PA fluoro	44	4	23	90	32	378.6
GI - Colon	Colon - Air C.	Obl.	44	4	27	90	20	262.7
GI - Colon	Colon - Air C.	Sigmoid	44	4	23	90	32	378.6
GI - Colon	Colon - Air C.	Lat Rectum	44	4	30	90	80	1140.5
GI - Colon	Colon - Air C.	Decubitus	44	0	23	90	12.5	116.0
GI - Colon	Colon	AP/PA fluoro	44	4	23	120	6.4	125.8
GI - Colon	Colon	Obl.	44	4	27	120	8	174.5
GI - Colon	Colon	Sigmoid	44	4	23	120	20	393.0
GI - Colon	Colon	Lat Rectum	44	4	30	120	40	947.1
GI - Colon	Colon	Post Evac.	44	4	23	100	20	286.7
GI - Colon	Coln-Gastrografin	Lat	44	4	30	90	6.4	91.2
GI - Colon	Coln-Gastrografin	Obl.	44	4	27	80	6.4	67.0
GI - Colon	Coln-Gastrografin	Lat Rectum	44	4	30	100	10	172.7
GI - Colon	Coln-Gastrografin	Sigmoid	44	4	23	100	20	286.7

E. Entrance-Skin-Exposure Assessed by Procedure (Con't):

General Site	Specific Site	View	SID (in)	TTID (in)	Thick (cm)	kVp	mAs	Exposure (mR)
Urography	Intraveous Pyelogram		44	4	23	70	32	228.1
Urography	Cystogram	AP/PA/Oblique	44	4	23	80	25	235.7
Urography	Cystogram	Lat	44	4	30	85	80	1023.5
Extrem.-Upper	Finger	PA/Lat/Obl	44	0	2	44	2.5	2.1
Extrem.-Upper	Hand	PA/Obl	44	0	5	46	2.5	2.7
Extrem.-Upper	Hand	Lat	44	0	5	55	3.2	6.7
Extrem.-Upper	Wrist	PA/Obl/Radial	44	0	5	50	3.2	4.9
Extrem.-Upper	Wrist	Lat.	44	0	5	55	3.2	6.7
Extrem.-Upper	Wrist	Carpel Tunnel	44	0	5	60	3.2	8.5
Extrem.-Upper	Forearm	AP/Lat	44	0	7	55	3.2	7.0
Extrem.-Upper	Elbow	AP/Lat/Obl	44	0	7	55	4	8.7
Extrem.-Upper	Humerous	AP/Lat	44	0	7	65	4	13.5
Extrem.-Upper	Humerous	Transthoracic	44	4	8	75	80	466.2
Extrem.-Upper	Shoulder	AP/Rotations	44	4	16	70	10	60.1
Extrem.-Upper	Shoulder	Axillary View	44	0	16	65	20	81.0
Extrem.-Upper	Sternocavicular	PA/RAO/LAO	44	4	16	70	10	60.1
Extrem.-Upper	Acromio-Clavicular	AC Joints	44	4	16	70	12.5	75.1
Extrem.-Upper	Clavicle	AP/Angle	44	4	20	70	10	66.1
Extrem.-Upper	Scapula	AP	44	4	20	70	20	132.3
Extrem.-Upper	Scapula	Lat	44	4	20	75	10	76.7
Extrem. - Lower	Pelvis	AP	44	4	23	70	25	178.2
Extrem. - Lower	Hip	AP/Frog	44	4	21	70	25	169.4
Extrem. - Lower	Hip	True Lateral	44	0	28	80	64	531.3
Extrem. - Lower	Femur	Proximal/AP	44	4	17	70	20	123.0
Extrem. - Lower	Femur	Distal/AP	44	4	17	70	10	61.5
Extrem. - Lower	Femur	Lateral	44	4	17	70	16	98.4
Extrem. - Lower	Knee	AP	44	4	12	70	5	27.4
Extrem. - Lower	Knee	Lat.	44	4	12	65	6.4	29.6
Extrem. - Lower	Knee	Tunnel	44	4	12	68	8	41.1
Extrem. - Lower	Knee	Patella	44	0	12	73	5	24.2
Extrem. - Lower	Tibia-Fibula	AP	44	0	12	65	1	3.7
Extrem. - Lower	Tibia-Fibula	Lat	44	0	12	65	1	3.7
Extrem. - Lower	Ankle	AP/Oblique	44	0	10	58	3.2	8.6
Extrem. - Lower	Ankle	Lateral	44	0	10	56	3.2	7.8
Extrem. - Lower	Oscalcis	Tangential	44	0	10	60	5	14.7
Extrem. - Lower	Oscalcis	Lateral	44	0	10	55	3.2	7.4
Extrem. - Lower	Foot	AP/Oblique	44	0	5	48	3.2	4.2
Extrem. - Lower	Foot	Lateral	44	0	5	58	3.2	7.8
Extrem. - Lower	Toe	AP/Lat/Obl	44	0	2	45	3.2	3.0

APPENDIX B

APPENDIX B: SPREADSHEET FOR TRACKING ENTRANCE-SKIN-EXPOSURES IN FLUOROSCOPY

JCAHO IPER AND ENTRANCE-SKIN-EXPOSURE RATES FOR FLUOROSCOPY

A. Fluoroscopic IPER: System: Tomographic Unit, Room 1, Lakenheath

Position 21 cm phantom on table top, remove grid, center large volume ion chamber on II

Normal collimation with ABC, II-TT = 12"

HLC	II Mode	kVp	mA	mR/min	uR/frame	Level OK (See Chap 3)
Low	Normal				0	
Low	Mag 1				0	
Low	Mag 2				0	
Medium	Normal				0	
Medium	Mag 1				0	
Medium	Mag 2				0	
High	Normal				0	
High	Mag 1				0	
High	Mag 2				0	

B. Spot Film, PhotofluoroSpot and Cine IPE:

Position 21 cm phantom on table top, center large volume ion chamber on II, II-TT=12"

Grid should be in-place, with the ion chamber preferably behind it, Normal collimation with ABC

Image	Grid	Other Cond	kVp	mAs	uR/image	Level OK (See Chap 3)
Spot Film	Yes					
Spot Film	Yes					
Spot Film	No					
Spot Film	No					
Photoflouro	Yes					
Photoflouro	Yes					
Photoflouro	No					
Photoflouro	No					
Cine	Yes					
Cine	Yes					
Cine	No					
Cine	No					

C. DSA IPE:

Position 21 cm phantom on table top, center large volume ion chamber on II, II-TT=12"

Grid should be inplace, with Ion chamber preferably behind it, Normal collimation with ABC

HLC	II Mode	kVp	mAs/frame	uR/frame	Level OK (See Chap 3)
Low	Normal				
Low	Mag 1				
Low	Mag 2				
Medium	Normal				
Medium	Mag 1				
Medium	Mag 2				
High	Normal				
High	Mag 1				
High	Mag 2				

D. Maximum Patient Entrance-Skin-Exposure Rate (ESER):

Place the 10 to 15 cc ion chamber on the table top, and center the II on the chamber.
Support two 3mm sheets of lead above the chamber using ~2" spacers
Grid should be in-place. Normal collimation with ABC, Normal II Mode, II-TT=12"

HLC	II Mode	kVp	R/min	Within Limits? (See Chap 3)
Low	Normal	60		
Low	Normal	80		
Low	Normal	100		
Low	Normal	max		
Medium	Normal	60		
Medium	Normal	80		
Medium	Normal	100		
Medium	Normal	max		
High	Normal	60		
High	Normal	80		
High	Normal	100		
High	Normal	max		

E. Patient Fluoroscopic Entrance-Skin-Exposure Rates (ESER):

Place the 10 to 15 cc ion chamber on the table top, and center the II on the chamber.
Support 21 cm PEP above the chamber using ~2" spacers: (Optional: 4",6" and 8" PEP)
Measurement w/ and w.o. grid, Normal collimation with ABC, II-TT=12"

Phantom	HLC	II Mode	Grid	kVp	mA	R/min
21cm	Low	Normal	Yes			
21cm	Low	Mag 1	Yes			
21cm	Low	Mag 2	Yes			
21cm	Low	Mag 3	Yes			
21cm	Medium	Normal	Yes			
21cm	Medium	Mag 1	Yes			
21cm	Medium	Mag 2	Yes			
21cm	Medium	Mag 3	Yes			
21cm	High	Normal	Yes			
21cm	High	Mag 1	Yes			
21cm	High	Mag 2	Yes			
21cm	High	Mag 3	Yes			
21cm	Low	Normal	No			
21cm	Low	Mag 1	No			
21cm	Low	Mag 2	No			
21cm	Low	Mag 3	No			
21cm	Medium	Normal	No			
21cm	Medium	Mag 1	No			
21cm	Medium	Mag 2	No			
21cm	Medium	Mag 3	No			
21cm	High	Normal	No			
21cm	High	Mag 1	No			
21cm	High	Mag 2	No			
21cm	High	Mag 3	No			

F. Patient Entrance-Skin-Exposures (ESEs) for Spot, PFS, and Cine:

Place the 10 to 15 cc ion chamber on the table top, and center the II on the chamber.
Support 21 cm PEP above the chamber using ~2" spacers: (Optional: 4",6" and 8" PEP)
Measurement w/ and w.o. grid, Normal collimation with ABC, II-TT=12"

Phantom	Image	Grid	Other Cond.	kVp	mAs	mR/image	OD	Level OK (See Chap 3)
21cm	Spot Film	Yes						
21cm	Spot Film	Yes						
21cm	Spot Film	No						
21cm	Spot Film	No						
21cm	Photoflouro	Yes						
21cm	Photoflouro	Yes						
21cm	Photoflouro	No						
21cm	Photoflouro	No						
21cm	Cine	Yes						
21cm	Cine	Yes						
21cm	Cine	No						
21cm	Cine	No						
15cm	Spot Film	Yes						
15cm	Spot Film	Yes						
15cm	Spot Film	No						
15cm	Spot Film	No						
15cm	Photoflouro	Yes						
15cm	Photoflouro	Yes						
15cm	Photoflouro	No						
15cm	Photoflouro	No						
15cm	Cine	Yes						
15cm	Cine	Yes						
15cm	Cine	No						
15cm	Cine	No						
10cm	Spot Film	Yes						
10cm	Spot Film	Yes						
10cm	Spot Film	No						
10cm	Spot Film	No						
10cm	Photoflouro	Yes						
10cm	Photoflouro	Yes						
10cm	Photoflouro	No						
10cm	Photoflouro	No						
10cm	Cine	Yes						
10cm	Cine	Yes						
10cm	Cine	No						
10cm	Cine	No						

APPENDIX C

APPENDIX C: SPREADSHEET FOR TRACKING AND CALCULATING MULTIPLE SCAN AVERAGE DOSE (MSAD) IN COMPUTED TOMOGRAPHY

1. The spreadsheet is in four sections to allow determination of MSAD for skull, thoracic, abdominal and pelvic procedures.

2. Fill out the appropriate data (red font cells) in each section for both the phantom center, and phantom surface exposures.

3. For a range of slice thicknesses, enter the measured exposure (in mR) recorded with the pencil ion chamber using typical techniques for a single scan.

4. Enter an appropriate slice separation for each slice thickness. The CTDI and MSAD are calculated automatically.

JCAHO CT MSAD for 16 and 32 cm Phantoms

Date: _____

A. Head Phantom (16 cm) - Skull Techniques

Unit: _____

Dosimeter Calibration and Correction for Head Phantom

f-factor= 0.94 $rad_{tissue}/R_{air\ (120\ kVp)}$

CF= 1 (120 kVp)

l= 100 mm (Chamber length)

Chamber Center Location:					Chamber Anterior Surface (max dose) Location:				
	Scan Angle	360 degree				Scan Angle	360 degree		
	Field Size:	20 cm				Field Size:	20 cm		
	kVp:	120				kVp:	120		
	mAs:	300				mAs:	300		
Slice Thickness (mm)	Chamber Reading (mR)	CTDI (mrad)	Slice Separation (mm)	MSAD (mrad)	Slice Thickness (mm)	Chamber Reading (mR)	CTDI (mrad)	Slice Separation (mm)	MSAD (mrad)
2		0	2	0	2		0	2	0
3		0	3	0	3		0	3	0
4		0	4	0	4		0	4	0
5		0	5	0	5		0	5	0
6		0	6	0	6		0	6	0
7		0	7	0	7		0	7	0
8		0	8	0	8		0	8	0
9		0	9	0	9		0	9	0
10		0	10	0	10		0	10	0

B. Abdominal Phantom (32 cm) - Thoracic Techniques

Dosimeter Calibration and Correction for Abdominal Phantom - Thoracic Techniques

f-factor= 0.94 $rad_{tissue}/R_{air\ (120\ kVp)}$

CF= 1 (120 kVp)

l= 100 mm (Chamber length)

Chamber Center Location:					Chamber Anterior Surface (max dose) Location:				
	Scan Angle	360 degree				Scan Angle	360 degree		
	Field Size:	40 cm				Field Size:	40 cm		
	kVp:	137				kVp:	137		
	mAs:	150				mAs:	150		
Slice Thickness (mm)	Chamber Reading (mR)	CTDI (mrad)	Slice Separation (mm)	MSAD (mrad)	Slice Thickness (mm)	Chamber Reading (mR)	CTDI (mrad)	Slice Separation (mm)	MSAD (mrad)
2		0	2	0	2		0	2	0
3		0	3	0	3		0	3	0
4		0	4	0	4		0	4	0
5		0	5	0	5		0	5	0
6		0	6	0	6		0	6	0
7		0	7	0	7		0	7	0
8		0	8	0	8		0	8	0
9		0	9	0	9		0	9	0
10		0	10	0	10		0	10	0

C. Abdominal Phantom (32 cm) Abdominal Techniques

Dosimeter Calibration and Correction for Head Phantom

f-factor= 0.94 $rad_{tissue}/R_{air\ (120\ kVp)}$

CF= 1 (120 kVp)

l= 100 mm (Chamber length)

Chamber Center					Chamber Anterior Surface (max dose)				
Location:					Location:				
Scan Angle	360 degree				Scan Angle	360 degree			
Field Size:	20 cm				Field Size:	20 cm			
kVp:	120				kVp:	120			
mAs:	210				mAs:	210			
Slice Thickness (mm)	Chamber Reading (mR)	CTDI (mrad)	Slice Separation (mm)	MSAD (mrad)	Slice Thickness (mm)	Chamber Reading (mR)	CTDI (mrad)	Slice Separation (mm)	MSAD (mrad)
2		0	2	0	2		0	2	0
3		0	3	0	3		0	3	0
4		0	4	0	4		0	4	0
5		0	5	0	5		0	5	0
6		0	6	0	6		0	6	0
7		0	7	0	7		0	7	0
8		0	8	0	8		0	8	0
9		0	9	0	9		0	9	0
10		0	10	0	10		0	10	0

D. Abdominal Phantom (32 cm) - Pelvic Techniques

Dosimeter Calibration and Correction for Abdominal Phantom - Thoracic Techniques

f-factor= 0.94 $rad_{tissue}/R_{air\ (120\ kVp)}$

CF= 1 (120 kVp)

l= 100 mm (Chamber length)

Chamber Center					Chamber Anterior Surface (max dose)				
Location:					Location:				
Scan Angle	360 degree				Scan Angle	360 degree			
Field Size:	40 cm				Field Size:	40 cm			
kVp:	137				kVp:	137			
mAs:	340				mAs:	340			
Slice Thickness (mm)	Chamber Reading (mR)	CTDI (mrad)	Slice Separation (mm)	MSAD (mrad)	Slice Thickness (mm)	Chamber Reading (mR)	CTDI (mrad)	Slice Separation (mm)	MSAD (mrad)
2		0	2	0	2		0	2	0
3		0	3	0	3		0	3	0
4		0	4	0	4		0	4	0
5		0	5	0	5		0	5	0
6		0	6	0	6		0	6	0
7		0	7	0	7		0	7	0
8		0	8	0	8		0	8	0
9		0	9	0	9		0	9	0
10		0	10	0	10		0	10	0

APPENDIX D

APPENDIX D: SPREADSHEET FOR TRACKING AND CALCULATING ENTRANCE-SKIN-EXPOSURE AND MEAN GLANDULAR DOSE IN MAMMOGRAPHY

1. Fill in the top portion of the form with the characteristics of the system used when measuring entrance exposures. Be sure to include an energy correction factor (if provided) for the probe used with the measurements. If none is provided a default value of 1 should be used.

2. For a range of three kVps, fill in the breast thickness (typically 4.2 cm), fraction of glandular tissue (typically 0.5), the target filter combination (MoMo, MoRh, RhRh), kVp, HVL, mA, time, density setting, magnification factor and focal spot size.

3. Input the measured exposure and OD for four consecutive exposures at each of the three kVp settings.

4. The spreadsheet determines the average exposure and the normalized mean glandular dose per unit exposure (the dose conversion factor), based on the filter/target combination, HVL and kVp entered.

5. Compare the calculated man glandular dose against the acceptance criteria.

6. Repeat for MoRh and RhRh target/filter combinations, and other breast thicknesses as appropriate.

ACR ESE AND MGD ASSESSMENT FOR BREAST

Date: 7-Nov-97

Unit:

Dosimetry System:	MDH 1515, SN 1234				Energy Correction:	1
Image Mode:	Grid:		Contact:		Magnif:	
Image Receptor:		Size:	18	cm X	24	cm
Field Restriction:	Standard Insert, Large Focus					
SID:	66	cm				
AEC Sensor Position:	Under Center of Phantom					

Breast Thickness (cm)	4.2	4.2	4.2
Glandular Fraction	0.5	0.5	0.5
Target/Filtration:	MoMo	MoMo	MoMo
kVp Setting:	25	26	28
HVL @ kVp:	0.33	0.35	0.37
mA setting:			
Density Setting:	Normal	Normal	Normal
Mag Factor @ center of breast	1.06X	1.06X	1.06X
Focal Spot	Large	Large	Large

Measured Entrance Exposure (mR)	R	mAs	R	mAs	R	mAs
Exposure #1	0.817	123	0.701	91	0.529	52
Exposure #2	0.814	123	0.701	91	0.53	52
Exposure #3	0.815	123	0.701	91	0.529	52
Exposure #4	0.813	123	0.7	91	0.529	52
Mean Values:	0.81	123.00	0.70	91.00	0.53	52.00
Standard Deviation:	0.0017	0.00	0.00	0.00	0.00	0.00
Coefficient Variation:	0.00	0.00	0.00	0.00	0.00	0.00

Energy Corrected Exposure	0.815	0.701	0.529
Dose Conversion Factor	165.05	175.49	186.49
Computed Average Glandular Dose	134.47	122.97	98.70

Acceptance Criteria: If coefficient of variation for either R or mAs exceeds 0.05, seek service.
If average glandular dose < 300 for a 4.2 cm effective breast thickness, adjust technique or seek service